# Demand-Side Management and Electricity End-Use Efficiency

Edited by

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# THE SUCCESSES OF CONSERVATION

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## 1. INTRODUCTION

People who have worked in the field of conservation have a lot to be proud of. In the last 14 years, we have made dramatic improvements in the efficiency with which we use energy, and have made an impressive head start on weaning ourselves away from our fossil fuel habit. We'll be looking at how far the U.S. and OECD have come, and looking ahead a bit to some accomplishments in the not-too-distant future. We'll talk about conservation in general, but most of our examples will focus on buildings, the sector we know best and one that accounts for 38% of the $440 Billion annual U.S. energy bill.

## 2. CONSERVATION HAS TEMPORARILY OVERWHELMED OPEC

### 2.1. Savings in the U.S. and within the OECD

The first point to remember is that we have saved a truly staggering amount of energy through conservation—by which we mean efficiency improvements, not freezing in the dark—since the first oil embargo. We introduce Figure 1 to illustrate these savings, which have accelerated since the second and more serious oil price shock in 1979.

Before 1973, energy prices were low and there was little interest in improving our efficiency. It was conventional wisdom that energy use would grow at least as fast as GNP. In Figure 1a (for the U.S.), the heavy solid line represents the actual consumption of total primary energy. The lighter solid line is simply GNP, scaled to go through the 1973 energy use of 73 quadrillion BTUs (73 "quads"). Backcast to 1965, we see that GNP and energy use tracked nicely, corresponding to frozen efficiency, but forecast to '85 we see GNP rising 33%, while actual use has leveled off at 73 quads. Thus we have achieved an astounding 33% increase in efficiency, and a remarkable annual saving of $150 Billion, but are still left with a $440 Billion annual energy bill.

In the figure, the broken lines represent oil plus natural gas, which are partially interchangeable in our economy since many boilers switch from one fuel to the other depending on the price. Despite the 33% growth in our GNP, our oil & gas use has declined even faster than our (also declining) domestic production of fossil fuels (indicated by the dotted line). Compared to 1973, we are now annually saving ½ of OPEC's current capacity of 29 million barrels of oil/day. We believe that if the U.S. and OECD had not reduced our need for this oil and gas, it could have come only



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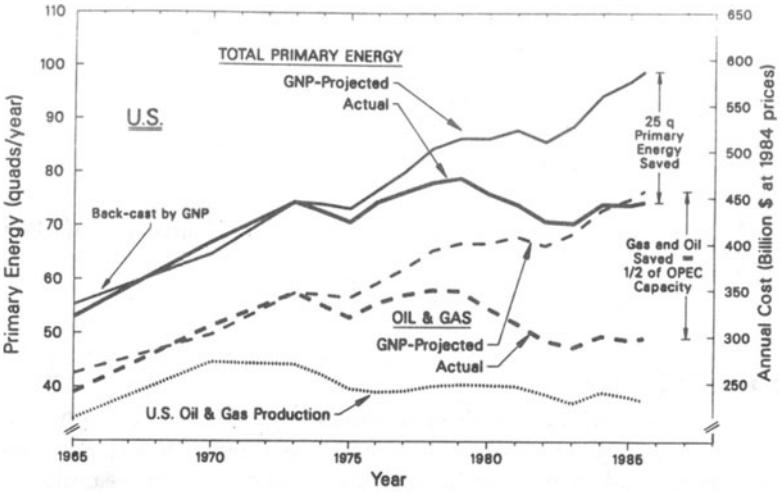
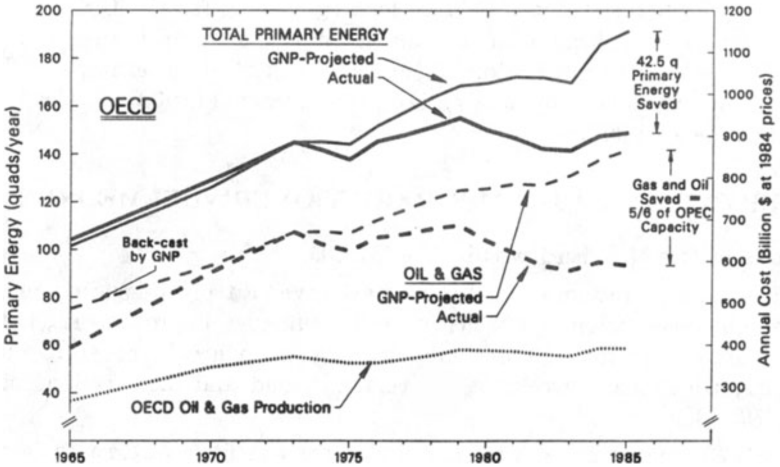



1a.




1b.

FIGURE 1a and 1b. U.S. and OECD Energy Use: Actual and Projected by GNP. The upper figure is for the U.S. and the lower figure shows comparable data for the entire the Organization for Economic Cooperation and Development (OECD). Projected energy is calculated on a GNP basis in constant dollars, with both forecast and "back-cast" values from 1973. Note that the GNP back-cast generally follows the actual consumption curve before OPEC. The "primary energy" on the left-hand scales includes fuel burned at the power plant, in units of "quads" [quadrillion ($10^{15}$ Btu]. The oil and gas savings were converted from quads to fractions of OPEC capacity using an estimated 1986 total OPEC production capacity of 29 Million barrels per day (58 quads). For the right-hand scales, quads were converted to 1985 dollars using the 1984 U.S. cost of energy (about $440 billion for 73 quads). Savings for the U.S. in 1985 were one-half of OPEC total capacity. The OECD includes all of North America, Western Europe, Japan, and Australasia, and consumes about twice as much total resource energy as the U.S. alone. Oil and gas savings for the OECD in 1985 were five-sixths of total OPEC capacity.

from imports, since our domestic production is steadily declining.

Figure 1b tells the same story for the OECD, which includes all of North America, Western Europe, and Japan. The OECD annual energy bill is $900 B, but (compared to 1973 efficiency) we are saving $250 B/year. Our oil & gas savings are 5/6 of current OPEC capacity. Because of the North Sea, OECD production of oil and gas is still rising, but nowhere near enough to supply the amount that we have saved. So, again, OECD imports would be nearly 5/6 of OPEC capacity higher.

What would we be paying today for oil and gas if OPEC were at 100% of capacity, and in addition there were still a major shortage of oil? Figure 2, taken from DOE/EIA's International Energy Outlook, hints at the answer—OPEC was able to raise prices in all those years that 80% or more of its capacity was in use. This suggests substantial price increases every year above the $30/barrel which we paid in 1980, disastrous increases of $100, $200, or even $300 Billion in our trade and budget deficits, and a global security problem, compared to which the present problems in the Persian Gulf pale into insignificance.

We conclude that conservation has bought us valuable time, and that we had best continue to support this winning strategy. But how long can we maintain the "glut," i.e., keep OPEC down to 60% of its capacity?

A vigorous government/utility conservation program can continue the flat demand of Figure 1 almost indefinitely, despite a reasonable growth in GNP. But oil production is going to drop, faster and faster for the U.S., and will peak in about 10 years for the North Sea and for the Soviets. Even OPEC, running at full capacity, is good for only about another 40 years.

Figure 1 covers only 20 years, so the decline in production does not appear very steep. Lest the viewer be deceived, we present Figure 3 on U.S. oil production, which goes out past 2020, when our children will still be paying energy bills but living without much domestic oil. The figure comes from *Beyond Oil*, by the Complex Systems Research Center, of the University of New Hampshire. It shows our inexorable decline in oil production. To emphasize this, its authors point out that in the 1950s we discovered 50 barrels of oil for every barrel invested in drilling and pumping. Today the ratio is 5:1, and by about 2000 it will have dropped to 1:1, at which time domestic exploration will become uneconomic.

What is more, the two smooth curves reflect reserves at a time when oil was very inexpensive. We spent $¼ *Trillion* exploring for oil in the 1980s. The bullets to the right of the curves show that this has bought us a mere 8-year delay in the day of reckoning.

Note that buildings generally last for 50 years, so a sub-optimal building constructed today will still be guzzling expensive energy long after American oil and gas have run dry. And today's buildings are very sub-optimal, as can be seen by noting American ideas about acceptable payback times. Builders (including the U.S. government) will not tie up their money in efficiency investments if the payback time is more than 2-3 years; yet, on the supply side, the typical investor will accept a payback time of 25-30 years from a power plant or an oil-and-gas venture. So the playing field is badly tilted in favor of supply. Thus a conservation measure such as thermal storage, which avoids running air conditioners at peak power times, has a payback time of only 2-3 years yet is largely ignored (and completely ignored in new federal buildings). If we persist in ignoring thermal storage until the turn of the

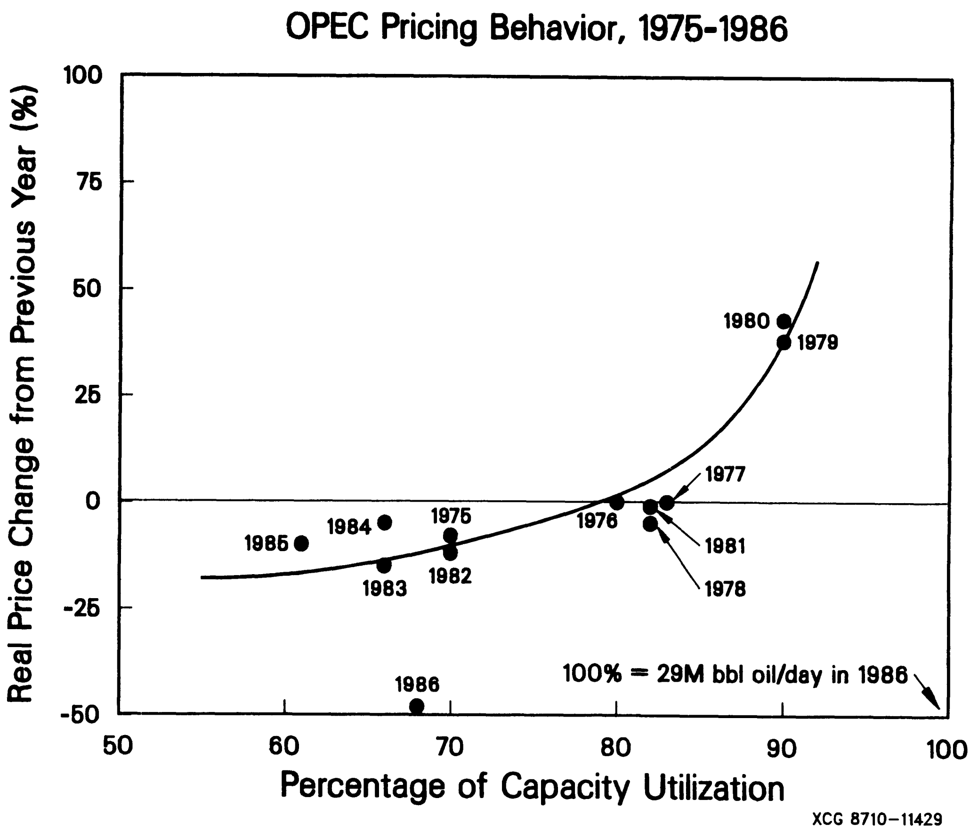



FIGURE 2. OPEC Pricing Behavior, 1975-1986. The 1986 observation, which was not used to derive the curve, reflects Saudi Arabia's decision to switch from providing price support to increasing market share. Figure adapted from: *International Energy Outlook, 1986.* Energy Information Administration, U.S. Department of Energy, page 10.

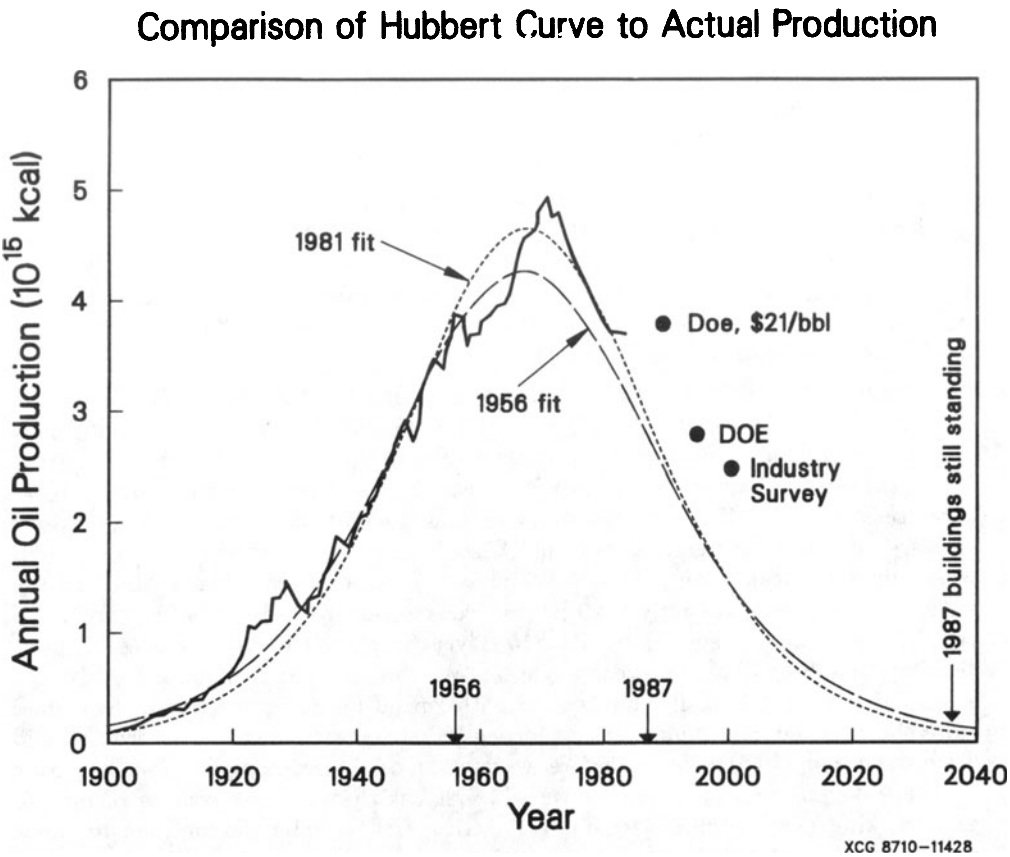



FIGURE 3. Comparison of Hubbert Oil-Depletion Curve to Actual Production, excluding Alaska. Solid line is actual U.S. oil production; dotted line is Hubbert's 1956 curve; dashed-dotted line is Hubbert's curve updated by authors of *Beyond Oil* based on 1981 data. Source: *Beyond Oil,* by the Complex Systems Research Center, University of New Hampshire, Ballinger Publishing, 1986. DOE Estimates for 1990 (6.9 Mbod) and for 1995 (5.2 Mbod), and Oil Industry Survey for 2000 (median = 4.5 Mbod), are from Energy Security (DOE S-57, 1987) and "U.S. Oil Production," U.S. Office of Technology Assessment (Report E-349, 1987).

century, we'll have to build the equivalent of 100 otherwise unnecessary standard 1000-MW power plants at a cost that will probably exceed $1.5 Billion each.

Figure 4 (taken from *Electrical World*) shows the effect on electric utility construction expenditures of the conservation success of Figure 1. During the power plant overbuilding spree around 1980, we invested $50 B/year (12% of our annual capital investment in plants and equipment). Now we have 50 baseload plants (about 1000 MW each) in excess of current need, and utility construction is predicted by *Electrical World* first to fall to $17 B/year (leaving another 10% more of our capital formation for other productive investment), and then to rise to $40 B/year as electrical demand continues to grow at 2%/year. Conservation R&D today, leading to more-efficient use of electricity in 1995, can greatly delay and mitigate the need for this looming $40 B *annual* investment.

Figure 1 showed that conservation is now saving the U.S. $150 B/year, and we have cut our energy bill to "only" 11% of our GNP. But the Japanese only 5%. "Least-cost" calculations show that optimal investment would halve our energy use by the turn of the century (see Figure 5). This suggests the following analogy: if we were stuck at 1973 efficiency, we would be pouring $590 B worth of energy into a pipeline each year and getting out only $220 B in energy services. The rest—$370 B—would have leaked out. But we've already plugged more than a third of the leaks, and we now waste only $220 B/year, so we pour in "only" $440 B worth. To be fair, we are adding something like $15 B/year in retrofit costs—a modest amount yielding something like a one-year payback. We can save the remaining $220 B that is wasted—and cut in half what we currently spend on energy—three to five times more cheaply than continuing to pay for wasted energy. So our first priority should be to finish plugging the leaks, before we invest more in new supply. The longer we let the leaks continue, the quicker we will exhaust cheap, secure sources of oil and gas. Seeking new supplies—"draining America first"—while we continue to waste energy and backslide on auto efficiency, just hastens the depletion of our reserves; heightened efficiency saves the energy until it is really needed.

And how much has it cost to plug the leaks? So far, because we have been skimming the cream, conservation has typically been five times cheaper than purchasing energy. So to save $150 B/year, we have probably invested $30 B/year, leaving a net savings of $120 B/year. In terms of incentive programs by governments or utilities, we can do even better than 5:1. PG&E, the giant Northern California utility, boasts that in 1985 it spent $0.25 B on conservation programs, but avoided committing $1.75 B to new supply, a benefit/cost ratio of 7:1. To save the next $200 B/year, some of the cream will be gone, but least-cost analysts estimate that conservation will still be three times cheaper than supply.

### 2.2. We are losing the efficiency race with Japan

In 1985, the U.S. used 11.2% of its GNP for energy; Japan used 5%. Figure 6 clarifies this point and puts the efficiency—as measured by energy use per GDP—of other countries in perspective. The details of the figure are explained in the caption, but the summary is that we spend about 6% more of our GNP on energy than do the economical Japanese.

Japan is beating us not only in absolute energy efficiency, but in the rate of improvement. In the period plotted in Figure 6, Japan has improved its energy use

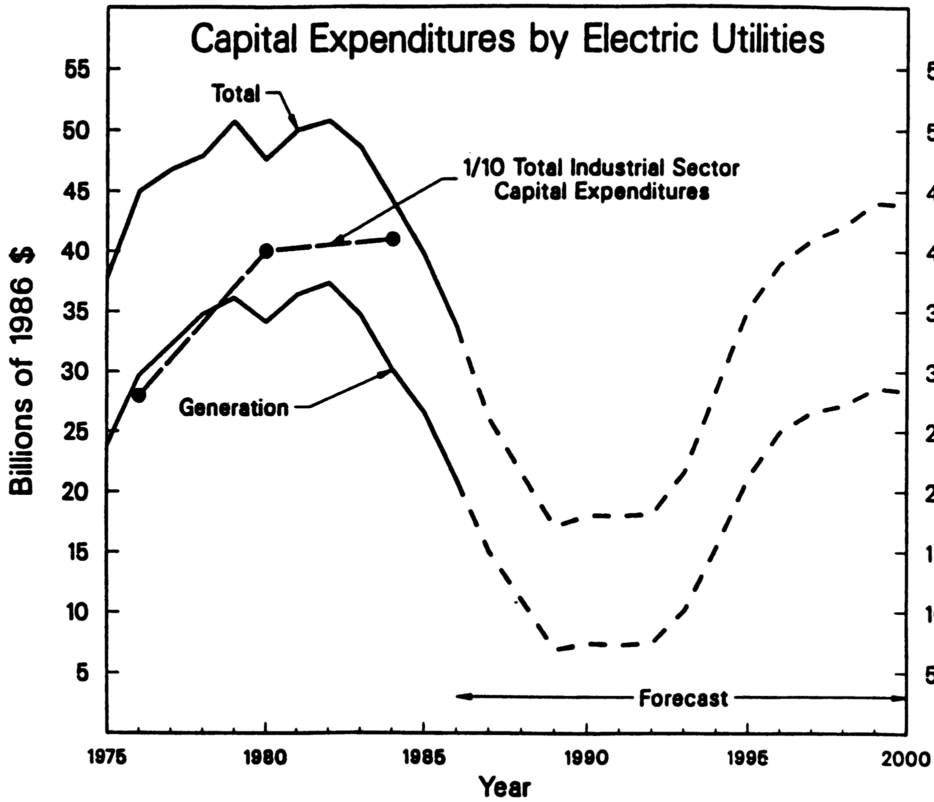



FIGURE 4. Electrical Industry Annual Investment in Plant and Equipment, in 1986$. The equivalent investment by all of industry is about $1B per day, so that the electric fraction has dropped from about 15% ($50B) to a minimum that will be about 5% ($17B). The utility investments do not include cogeneration, which is running at about $2B/year. Source: *Electrical World,* McGraw-Hill, Inc., September 1986. Figures for total industry investment are from *1986 Statistical Abstract of the United States,* 106th Edition, Table 901, p. 529, using GNP implicit price deflators to convert to 1986 dollars.

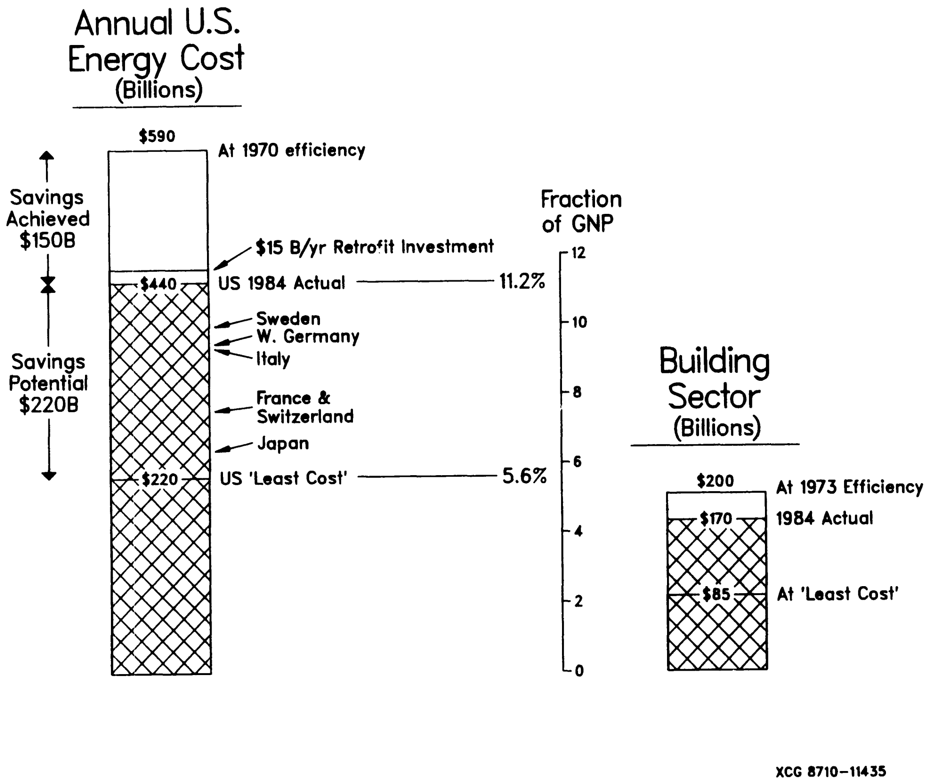



FIGURE 5. Annual U.S. Energy Cost. By 1984, the energy use per dollar of GNP (in constant dollars) has dropped to 74% of the 1970 level. If efficiencies had stayed frozen at 1970 values our $440-billion annual cost today would instead be $440 B/0.74 = $590B. On right scale, "Fraction of National GNP," are lines representing 1984 fractions for European countries and Japan. These lines show what the 1984 U.S. economy would pay for energy at various foreign efficiencies.

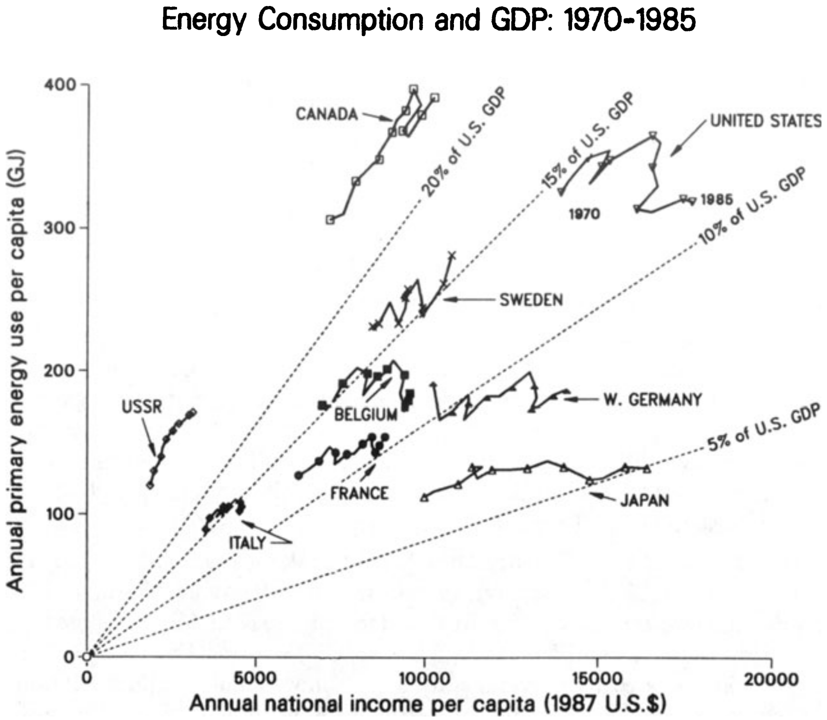



FIGURE 6. Resource Energy use vs. GDP (both per capita) for 9 Industrial Countries. Each country is represented by a sequence of points connected by straight lines, beginning in 1970 and ending in 1985. The conversion from local GDP to dollars depends only on the July 1 1987 exchange rate; earlier points are plotted using individual national deflators. For the lines labeled 5%, 10%, 15%, and 20% of U.S. GDP, we use an average 1987 price of resource energy of \$6.14/GJ. Hydroelectric and nuclear electricity are converted to resource (primary) energy using IEA's standard generation efficiency of 38.5% (except in Japan, 35.1%). Data for the USSR is unfortunately site energy. Sources: Price - DOE/EIA 0376-1984 (updated to 1985 by phone to EIA). Income and Population - IMF International Financial Statistics 1986. Energy Consumption - the OECD/IEA volume *Energy Balances 1970-1985* (it should be noted that we use the "Total Energy Requirement" data as opposed to "Total Final Consumption"; the former is resource (or "primary") energy and the latter is site energy, where the losses in electricity generation are ignored. Soviet Data - "UN Demographic Yearbook," 1985. Exchange rates are for July 1, 1987. 1 TOE = 42.6 G.

per dollar of GDP by 31%, while we have improved by only 23%. At the same time, Japan's per-capita income has come up from behind and is now passing that in the U.S.. Nevertheless we can be proud that we have the second best record of the nine countries pictured, thanks to appliance and automobile labels, automobile standards (*and* imported cars), building standards, federal and utility conservation programs, a vigorous R&D program, and of course the market.

How has Japan become as productive as the U.S. on less than half the energy? Between 1973 and 1985, energy use per pound of steel produced had declined by 15%, electricity used to operate new refrigerators had dropped by 73%, and electricity used to run room air conditioners has dropped 42%. [1]

New Japanese cars now average 29 mpg, their national policy is heading for 50-60 and their prototypes have already hit 100 mpg. In contrast, U.S. policy has been to backslide from 27.5 to 26 mpg—even when the incremental cost saves gasoline at 50¢/gallon—and instead to emphasize drilling for oil off the California coast, or in the Arctic National Wildlife Reserve. Ironically, if we can drain the controversial 3.5 $\pm$ 1.5 Billion barrels off of California in 30 years we will produce only 0.32 Mbod, just the amount lost in the fuel economy backslide.

Of course to achieve this efficiency they had to make investments, whose repayment eats into about 20% of their savings. So instead of having 6% more of their GNP available than we do, they really have gained only about 5%. We assert (and will explain below) that this differential of 5% of GNP means that, even if all else were equal, our products cost on average about 5% more than comparable Japanese products, thus impairing our balance of payments, the dollar/yen ratio, and our life-style.

Some readers may find this assertion obvious and can skip this paragraph, but those who are surprised at a 5% cost penalty should consider this argument. The total energy cost of any product is the sum of the direct energy cost (significant for iron and steel, insignificant for most high-tech products) *plus* the indirect cost embedded in wages. (For the same life-style, a U.S. worker who commutes in a gas guzzler and lives in a poorly insulated dwelling needs higher wages than his Japanese competitor.) Effectively, U.S. manufacturers pay a total 5% energy tax. But unlike other taxes, which arguably provide government services, this 5% just goes up in smoke and pollution.

The defense version of this tax is already much discussed. Thus, if the Japanese had a GNP equivalent to ours, they would avoid a tax of $300 B (7.5%) for defense, giving them a 7.5% competitive edge. Now we have added a $200 B (5%) energy-efficiency differential tax, for a total handicap of 12.5%—and as energy prices rise, this gap will widen.

Let us examine in more detail what will happen in 10 or 20 years if OPEC regains control and energy prices double. Without a continuing, vigorous conservation program, our energy bill could zoom from 10% to 20% of GNP. We predict that the Japanese will continue to invest in efficiency even during the glut, get down to 2% of GNP at today's cheap prices, and later climb back to only 4%. And they will be experienced at manufacturing and exporting energy-efficient products, which seem likely to be in demand. The competitive outlook begins to look bleak.

# 3. PUBLIC R&D FOR ENERGY

## 3.1. Conservation R&D compared with other economic sectors

**Table 1** disaggregates our $440 B annual energy bill according to the buildings, industry, and transport sectors and **Table 2** compares our total expenditure in several economic sectors with our publicly supported research and development effort in them. Despite the prominence of our national energy bill (the largest single sector), we invest barely ½ of 1 percent of that amount in research aimed at meeting our energy needs. If we consider R&D effort on construction and conservation (which can meet our needs at one-third to one-fifth the cost of new supply), we invest less than one-tenth of one percent. By comparison, for Defense, Health, and Agriculture R&D we spend anywhere from 1% to 12% of total expenses, or 10 to 100 times more than for conservation. But if we look at what really works, it is conservation that has (literally) fueled our post-OPEC economic growth.

Figure 7 shows the U.S. Department of Energy (DOE) budget over the last few years. It grows from its foundation in 1976 to a peak of $15 Billion a year, then comes down sharply under the Reagan administration. And only a small fraction of this has gone to improving energy efficiency. Most of this is military and in terms of raising our oil or coal production we haven't done anything. This misplacement of priorities isn't a sickness for which DOE is solely susceptible; it's a general trend in our society. If one looks at the Electric Power Research Institute's (EPRI) budget, for example, one sees that it's 6% demand-side and 94% supply-side research. We're very much a society that pays more attention to big aqueducts than to fixing leaky faucets; to large power plants than to many small and efficient lamps; to a rail line than to a flexible fleet of busses in urban areas; to a freeway than to well-timed street lights; to a hospital than to preventive health care.

In 1980, DOE was spending $100 million on Buildings and Community Systems research, or $1.20 per home in the United States. Remember the potential savings are around $2000 a home, aside from commercial buildings where a large savings potential also sits untapped. The Reagan administration thought that DOE was spending too much and requested zero budgets by 1983. Congress helped a bit and things haven't been zeroed out yet. We're now at 50 cents per home per year with Reagan asking for half of that for next year in the face of a 100-to-one return potential.

## 3.2. Technological triumphs of DOE-supported R&D

Technical successes of DOE-sponsored Buildings R&D were well documented in a 1986 Conservation White Paper [2], so we will summarize only a few points and reproduce its main table (**Table 3**).

In the White Paper, case histories were presented for three important technical developments: high-frequency, solid-state ballasts for fluorescent lamps (Figure 8), "heat-mirror" (low-E) window films, and improved refrigeration. The paybacks on federal R&D funding were typically 5000:1, but the delay times are long, partly because the buildings industry is so fragmented (see Figure 9). Thus, at LBL we started to develop the heat mirror film in 1976, but as shown in Figure 10 it will not reach 50% market penetration until around 2000 (13 years from now), and the majority of existing windows will not be replaced until 2020 (33 years from now). So to save scarce energy for our children, we need to support R&D today.

**TABLE 1.**
**U.S. Energy Expenses, 1985***

| Sector | Fuel ($10B) | Electricity ($10B) | Total ($10B) |
|---|---|---|---|
| **Buildings** | **60** | **110** | **170** |
| Residential | 40 | 60 | 100 |
| Commercial | 20 | 50 | 70 |
| **Industry** | **70** | **40** | **110** |
| Buildings | 3 | 7 | 10 |
| **Transport** | **160** | **0** | **160** |
| **TOTAL** | **290** | **150** | **440** |
| **Percent of GNP** | | | **11.2%** |

* Excluding Federal subsidies and rounded to the nearest $10 billion. Source: *State Energy Price and Expenditure Report 1985,* October 1987.

**TABLE 2.**
**Comparison of Energy Expenses and R&D**
**With Other Economic Sectors**

| | Total Expenses (Billions 1984$) | Publicly Supported R&D + Tech Transfer (Billions of 1985$) | Percentage of 1984$ |
|---|---|---|---|
| **Energy** | $440B | | |
| **Total Supply R&D** | | 2.50 | 0.5% |
| **Conservation R&D** | | 0.16 | <0.1% |
| **Health** | 400 | | |
| **N.I.H.** | | 6.20 | 1.6% |
| **Construction** | 340 | 0.01 | <0.01% |
| **Defense** | 300 | 37 | 12% |
| **Education** | 200 | <0.1 | <0.1% |
| **Federal Deficit** | 200 | --- | --- |
| **Trade Deficit** | 200 | --- | --- |
| **Agriculture** | 140 | --- | --- |
| **Experiment & Extension** | | 1.70 | 1.2% |

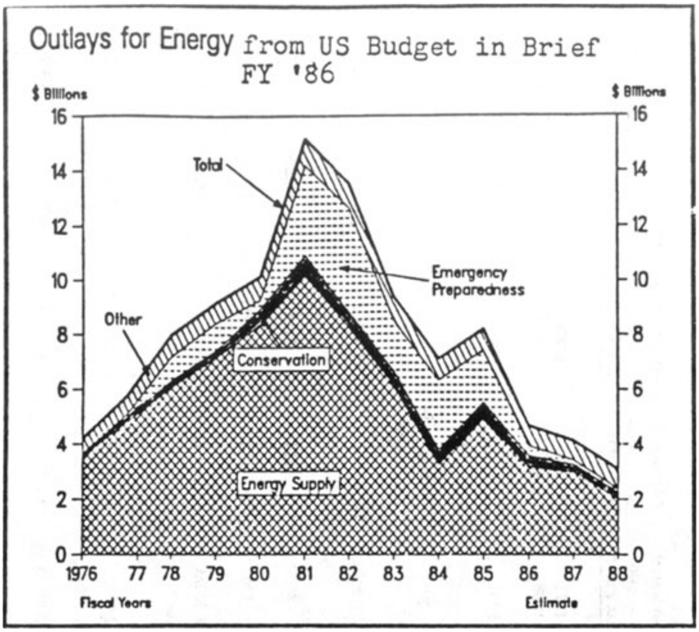



FIGURE 7. Trends in Outlays for Energy. Source: H. Richard Heedy, Rocky Mountain Institute, Testimony to Subcommittee on Energy and Agricultural Taxation, U.S. Committee on Finance, 21.VI.85. The total 1984 outlay was equivalent to 11% of the U.S. energy bill in that year. For detailed 1984 data, see *Energy Conservation Digest,* June 24, 1985.

## TABLE 3.

### Lead-times and Net Savings for Successful DOE-Sponsored Buildings Energy R&D Projects

| | Solid State Ballasts | Low-E Window Films | Residential Absorption Heat Pump | Advanced Electric Heat Pump | High Efficiency Refrigerator Compressor | High Efficiency Refrigerator -Freezer | Heat Pump Water Heater |
|---|---|---|---|---|---|---|---|
| 1. DOE Project Duration | 1976-1980 | 1976-1990[D] | 1978-1988 | 1977-1986 | 1977-1981 | 1978-1983 | 1977-1982 |
| 2. Est. 50% Penetration of Sales | 1995 | 2000 | 2001 | 1998 | 1990 | 1996 | 2000 |
| 3. Years by which DOE advanced commercialization | 5 yrs. | 5 yrs. | 5 yrs. | 2 yrs. | 2 yrs. | 2 yrs. | 2 yrs. |
| 4. Cost of Conserved Energy, (CCE) | 2¢/kWh | $2/MBtu | $2.50/MBtu | $2.75/MBtu | 1¢/kWh | 3¢/kWh | 5¢/kWh |
| 5. Cost of DOE Project | $3M | $2M | $6.8M | $2M | $1M | $0.8M | $0.7M |
| 6. Net Annual Savings in 1985 | $11M | $14M | $0M | $0M | $0.4M | $0.2M | $0.3M |
| 7. Net Annual Savings at Saturation (i.e. 10-15 after 50% penetration) | $5,000M | $3,000M | $2,400M | $2,500M | $1,100M | $850M | $1,800M |
| 8. Cumulative Net Savings (Line 7 x line 3) | $25,000M | $13,000M | $12,000M | $5,000M | $2,200M | $1,700M | $3,600M |
| 9. DOE Project ROI (Return on Investment, =Line 8 ÷ line 5) | 8,000: 1 | 7,000 : 1 | 1,500 : 1 | 2,500 : 1 | 2,000 : 1 | 2,000 : 1 | 5,300 : 1 |

Source: "Federal R&D on Energy Efficiency: A $50B Contribution to the U.S. Economy, a White Paper on the Consequences of Proposed FY'87 Budget Cuts," by the American Council for an Energy-Efficient Economy and the Energy Conservation Coalition. March 4, 1986.

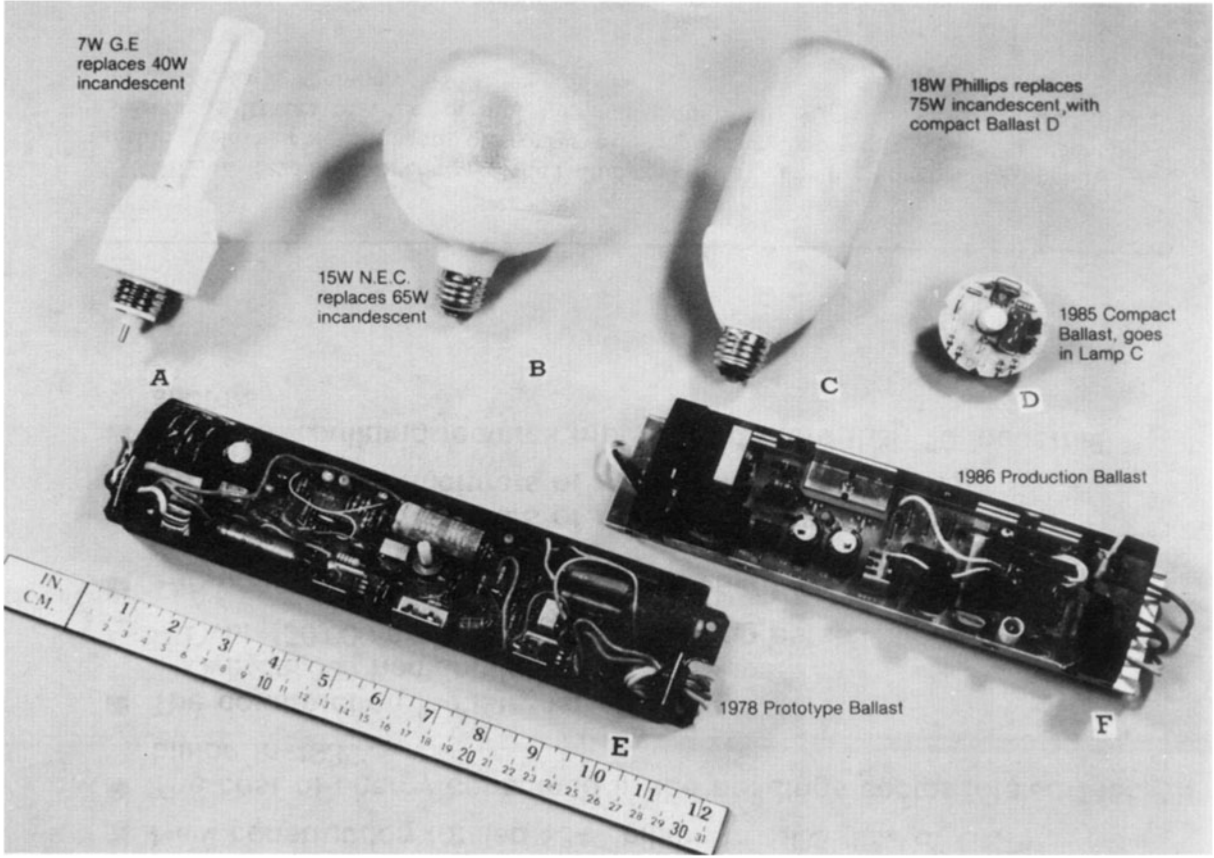



FIGURE 8. Energy Efficient Lamps and Ballasts.
Development, starting in 1978, of high-frequency, solid-state ballasts for fluorescent lamps; first for long tubes, later for compact fluorescents to replace less efficient incandescents.

## Size & Diversity of the Buildings Sector

- New construction totaled $340 billion in 1985 (9% of GNP)
- The cost of energy consumed in the buildings sector totaled $165 billion in 1985
- The construction industry is:
  - Over 28,000 homebuilders
  - Over 150,000 special trade contracting establishments
- The construction material and component manufacturing industries are also fragmented:
  - Over 600 manufacturers of non-electric heating equipment
  - Over 100 manufacturers of mineral wool insulation
- Each new building requires inputs from more than 50 industrial sectors

FIGURE 9. Size and Diversity of the Buildings Sector. The high degree of fragmentation delays the diffusion of conservation practices. Source: DOE Assistant Secretary's Review of Office of Buildings and Community Systems, Lawrence Berkeley Laboratory. October, 1986.

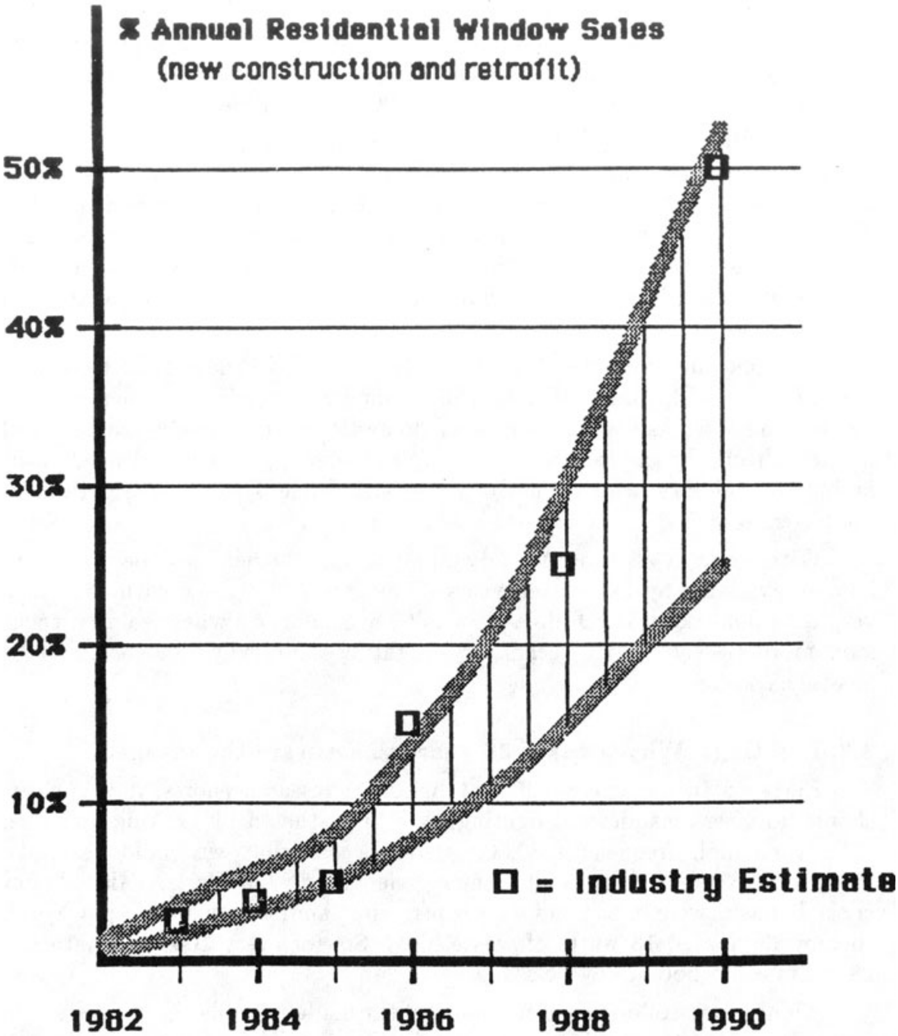



FIGURE 10. Industry Estimate of Low-E Windows Market Share based on Annual Sales. With a projected 20% market share in 1987, sales will be over 100 million square feet. Savings from cumulative installed window area will be approximately $60 million in 1987. At saturation of existing residential stock, savings will be $4-5 billion per year at current fuel prices. These savings will be equivalent to one-quarter of the output of the Alaska Pipeline.

The savings from these three completed projects are astounding, nearly $17 B/year when they finally saturate the market (even at today's prices). This equals the yearly output of about 25 baseload power plants, and an oil & gas saving equivalent to half the yearly output of the Alaska pipeline.

In addition to saving energy, conservation has also saved some U.S. industries and created others. The $1 B/year U.S. ballast market would have been invaded by the Japanese and the Europeans had it not been for U.S. development of the solid-state ballasts. In California, we have two new industries based on the "heat mirror" films: Southwall Technologies sells low-E coated plastic to window manufacturers, and Airco Solar Products sells multi-million dollar plants for sputtering the thin films on glass.

We conclude from the data in Table 3 that DOE-developed technologies have paid off very well, and that they will become commercial in America several years sooner than if we had waited for either domestic or (more likely) overseas industry to develop them. In the case of the examples above, several years' acceleration of the savings of $17 B/year (the sum of Row 8 of Table 3) represents a savings to U.S. ratepayers of $62 B.

With good R&D, we can advance the times when new demand-side options become available by five or ten years. Things are slow now with the low oil prices yet, if we don't keep R&D alive we won't have solutions when we need them. Let us look more closely at one technology—lighting—and why innovation and diffusion has taken so long.

### 3.3. Lighting: Why it takes 30 years to saturate the market

Early on in our energy-efficient buildings research efforts, it was clear that we should go after incandescent lighting. We knew that if by exciting fluorescent lamps at a very high frequency—30,000 Hertz or so—that we could gain about 15% efficiency. Regular fluorescent lamps cycle at only 60 Hertz. Also, before the oil crisis ballasts were made out of copper wire laminates which ran very warm and thereby dissipated 13 watts of waste heat. So, for every 100-watt fixture a total of 28 watts could potentially be saved.

Along came solid-state electronics which made possible the solid-state ballast, or more accurately the solid-state oscillator. Because they dissipated only a few watts of waste heat, the net efficiency gain was 20%. To this we added a photocell that looked down on the workspace and adjusted the intensity to make up the difference between the available daylight and the preferred lighting level.

Since lighting in the U.S. required 30 power plants, savings potential was phenomenal. We went to GE and were disappointed with their reluctance to adopt such innovations—they much preferred to wait for small companies to take the risks; when the technology and marketing were proven, the big boys would move in and buy the small guys out. Sylvania, Westinghouse, and Advanced Transformer (Phillips) told us the same story.

So, we went to ERDA—DOE's predecessor—and convinced them to support small R&D efforts with small companies. With 60 interested firms, we selected two and within six months had our first prototype; this was 1976. Then we went to our local utility, PG&E, and convinced them to let us showcase the ballasts and daylighting controls throughout three stories of their skyscraper in San Francisco. By the time the installation was debugged, we were saving 40%. Then we waited for two years and nothing happened. To our dismay, the underwriting labs—whose committees were chaired by representatives of the four big lighting companies—hadn't granted any approvals for the new technologies. Then, Beatrice Foods decided to become the fifth big actor and they bought out one of the small companies and within two weeks Westinghouse turned around and bought them back out for two million dollars. Then things started to move. Now we expect these new ballasts to saturate the market by about 1995.

The other lighting success story is the compact fluorescent, screw-in lamps like the Phillips SL-18 shown in Figure 9. The SL-18 replaces a standard 75-watt incandescent and provides the same lighting service for only 18 watts. What's more, it lasts 7500 hours, outliving the incandescent by 10 to 1.

What are the economics? Say we save 33%, or 33 watts for each 100-watt fixture. The cost of conserved energy is 2.5 cents per kilowatt hour and the payback is less than a year. During its 10-year life, it will save five barrels of oil and costs is a lot less. The combination of the new ballasts and compact fluorescents will save about $10 Billion a year when saturated into buildings in the United States.

What have we learned? For one thing, this business takes a long time. A ballast lasts about 10 years, so before they actually saturate all the buildings—the last of the old electricity guzzlers won't burn out until about 2005—it will be 30 years. Federal acceleration of R&D can make a huge difference in the implementation time and increase savings by billions of dollars.

## 4. COMPETITIVENESS NEEDS MAJOR ATTENTION

Despite the successes of the DOE R&D program that we have just described, the outlook for the U.S. energy-efficiency industries is clouded by our general inattention to new product development. DOE's conservation R&D program is far too small, and we have nothing in the U.S. comparable to Japan's MITI (Ministry of International Trade and Industry) or to the EEC's BRITE (Basic Research Industrial Technology for Europe). For many reasons, including its perception of the market, U.S. industry is not producing energy-efficient products: not cars, manufactured homes, air-conditioners, etc. (Aircraft are a notable exception). As we mentioned earlier, at LBL we had disappointing experiences in trying to interest large U.S. manufacturers in high-frequency ballasts or heat mirror films for windows.

The pattern is quite different in Japan, where R&D budgets are comparable to ours, but MITI can step in to manage and support commercialization of new, beautifully engineered, efficient, exportable products. Sometimes the original R&D was Japanese, but often it was American, acquired by licenses or technology agreements. It is well known that despite U.S. R&D on electronics, Japan has taken the front seat in the world market on VCRs and compact disks.

A similar pattern exists in another high-technology product line: efficient electric motors and controls. U.S. industrial, commercial, and residential consumers pay about $80 B/year for power used to run electric motors. Recent advances in magnetic materials and power electronics are greatly improving the efficiency of these motors and motor-driven systems, reducing costs to consumers. For example, permanent-magnet motors can have 20% lower losses than the best induction motors, run cooler, are smaller and lighter, and can be more precisely controlled.

Current applications include machine tools, robotics, computer peripherals, and home appliances.

A 1986 study [3] points out that:

> U.S. competitiveness in this rapidly growing market for new motor technologies is of concern, however. As pointed out the National Materials Advisory Board, 'The fundamental work leading to the REPMs [Rare-Earth Permanent Magnets] was done largely in the United States ... but after government support ceased, materials R&D in the U.S. magnets industry deteriorated. Practically all recent PM materials have been developed to commercial maturity in Japan.'
>
> Thus the NMAB concludes that 'despite the critical importance of magnetic materials, the U.S. is rapidly losing its competitive position.' And this in a market that is expected to reach $2 Billion annually next year.

The fast-growing market in power electronics (electronic devices which control power-consuming equipment) is also facing intense foreign competition. For example, electronic adjustable-speed drives (ASDs), which control the speed of electric motors subjected to varying loads and reduce electricity use by 20 to 30%, use basic components that were first developed by American companies. Nonetheless, foreign penetration of the U.S. market for ASDs has grown from 15% in 1980 to over 40% in 1985. Foreign companies have not only taken over the lead in production of ASDs, they have taken over the lead in innovation and product development.

Ralph Ferraro of the Electric Power Research Institute (EPRI) estimates that the U.S. manufacturers' share of the domestic power electronics market will erode from its present level of 50% to about 25% within five years. According to the Federation of Materials Societies, "if the current trend continues, it can be anticipated that the U.S. will be a minor force in the world market for electronic materials and systems by the 1990s".

A final example of competitive problems is in the area of housing technology, an industry that is traditionally seen in the U.S. as fragmented and slow to accept technical innovation. Contrast our situation with that of Sweden, where the government supports an ambitious R&D program in all aspects of basic and applied building technology. [4] Total funding is similar to that in the U.S., even though the Swedish market is only about one-twentieth the size of ours. Swedish researchers have produced a host of technical innovations that are already used in "superinsulated" homes around the world. Applications of R&D results to an industrialized building sector have made high-quality, energy-efficient homes the norm in Sweden, rather than the exception. Several firms are now exporting their factory-built housing to the U.S., and are beginning to compete successfully in upscale markets.

## 5. TEN YEARS OF CONSERVATION IN CALIFORNIA

On a more positive note, let's consider the experience we have had in California in attempting to institutionalize energy efficiency at the state government and utility level—an experience that has seemed slow at times but that has produced lasting results.

### 5.1. Innovative rate design

One of the first things that the utilities tried (after they were dragged into it by the Public Utilities Commission) was to invert their declining block rate structure and start charging more for electricity the more the customer used. This spurred a lot of conservation, because people's electric bills were now finally sending them the right signals: the cheapest block represented the utility's old, cheap power; the next block was the average cost; and the highest tier reflected the cost of building new plants or operating the utility's most expensive ones. Since then, because of a temporary surplus of generating capacity, average and marginal cost have veered so close to each other that there are only two tiers, but that situation probably won't last.

### 5.2. Appliance standards

One of the most successful programs we have tried in California are our appliance-efficiency standards. In 1976, right after the embargo, the state legislature passed a bill under their Title-20 jurisdiction that set maximum energy consumption levels for a variety of household appliances; those standards have since been adjusted to reflect vastly improved technology. We'll consider refrigerators, which, mundane though they may be, nonetheless account for 10 percent of the electricity used in the United States.

The time scale for Figure 11 starts in 1977, when the first standards were adopted, and runs through 1993, when the most stringent standards will take effect. These figures apply to a typical 15- to 18-cubic-foot top freezer with automatic defrost. The number of kilowatt-hours required to run the refrigerator each year has been ratcheted down from 1900, where it started out in 1977, to 1500 then to 1000, and will go down to 700 in 1993. The most important thing is that there is no change in the service the refrigerator provides. This is all for refrigerators which are designed to stay at 40 °F (4.5 °C) in the food compartment and 0 °F (-18 °C) in the freezer compartment. All that we've done is to double the efficiency.

How much does it cost (retail) to go from the old, inefficient refrigerator to the 1993 juice-sipping model? The California Energy Commission estimates $100. That doesn't mean $100 in production costs—the actual increase in factory cost of the refrigerator is only about $35. The typical mark-up in the refrigerator industry is 2.7 times (including marketing and advertising), plus a certain premium because this refrigerator is now marketed as "efficient".

What does society save by that $100 investment? At 8 cents per kilowatt-hour, the less-efficient refrigerator costs $150 per year to operate and the efficient one costs about $55 per year. The savings is about $100 per year on something which costs the manufacturer $35 once every 20 years to make. The payback period for society is either 1 year or 1/3 year, depending on how one looks at it.

With those annual savings of $100, the customer can pay off the retail surcost in the first year. The refrigerator lasts 19 more years, so the savings for the following 19 years are pure profit for the consumer.

Critics have charged that these refrigerator standards are "coercing the American public". Well, yes, they do coerce the public, but not very strongly. They force the public to do things with a one-year payback, not a ten-year or thirty-year payback as is the case with new power plants. Californians, at least, don't seem to mind being coerced to this extent.

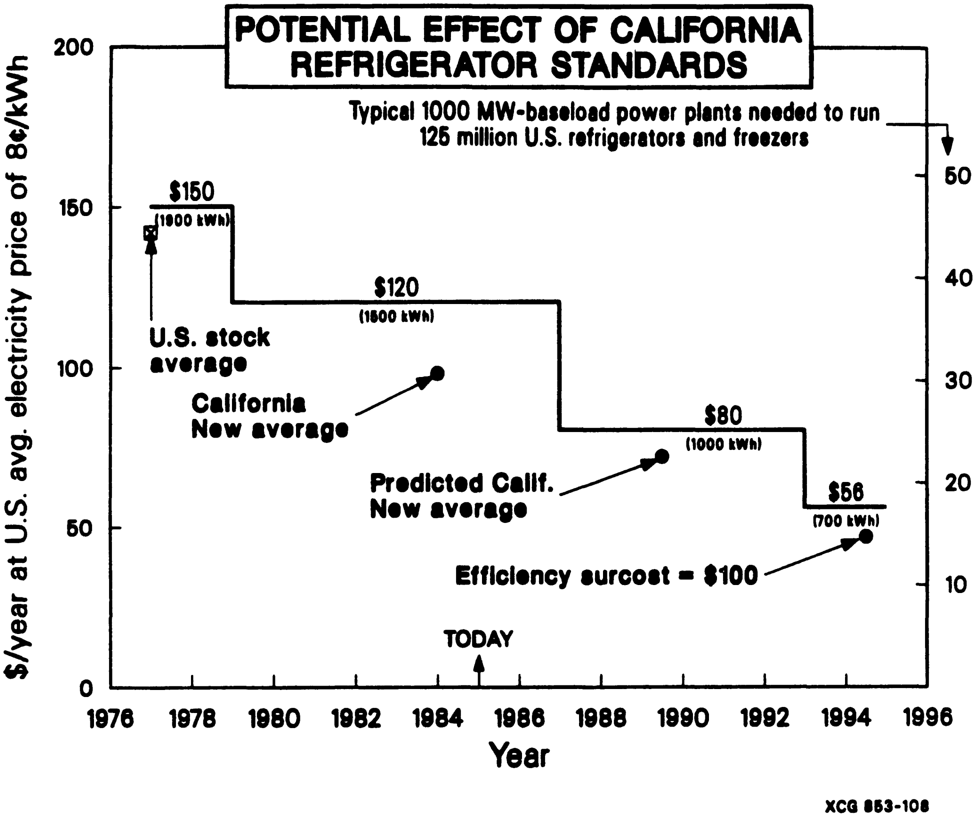



FIGURE 11. Potential Effect of California Refrigerator Standards if Adopted Nationwide. A typical 1000-MW baseload power plant produces 5 BkWh/year. The 125 million U.S. refrigerators consume 240 BkWh or 48 plants, assuming the average refrigerator today uses 1900 kWh/year. If the U.S. stock were to reach the average efficiency of 1994 refrigerators in California, we would be down to 700 kWh/year or 18 plants. Sources: California refrigerator consumption (stock and projected) - California Energy Commission press release, 21 December 1984 (Margaret Fjelsted). Refrigerator Stock - *1984 U.S. Statistical Abstracts*, pp. 755.

These standards have had a significant effect on electricity use throughout the United States. Since manufacturers can make a refrigerator that conforms to these standards for $35, they didn't bother to build new assembly lines to keep making crummier refrigerators than they could sell in California. So every new production line that's been set up since the California standards were enacted conforms to those standards. There is a little "dumping" at first. When California tightens its laws, then the manufacturers dump the bad ones on Texas (a favorite), but eventually all refrigerators tend to conform.

In the United States there are 90 million dwellings, but there are 125 million refrigerators and freezers. That is, the average saturation of refrigerators plus freezers is about one and a half. If refrigerators still used 1900 kWh/yr, it would take 50 power plants of the standard gigawatt size to run all of them* (right-hand scale, Figure 11). By the time we reach the 1993 standard, we'll be down to 18 plants or 18 gigawatts. The savings, then, are 32 GW, or 32 large central-station power plants. Recall that the payback for these savings is only one year.

Air conditioners tell much the same story and are now included in the national standard, discussed in section 7. Air conditioners in small commercial buildings are subject to the same sort of economics we talked about earlier. The California codes are usually based on trying to get a two- or three-year payback. Figure 12 shows the decrease in energy use and therefore dollar use by a three-ton air conditioner coming down from $410 a year for Fresno in 1977 to $290 a year. The COPs are improving from seven to ten. The surcost being about $300 to save 1.5 kilowatts with a cost to conserve power running at about $200 a kilowatt. If you can buy a lot of power at less than that, more power to you, but this seems to be a good way to do it compared to $1,750/kilowatt which is the cost of new capacity for the utility that serves Fresno.

### 5.3. Effects on statewide energy use

These and other strategies have had a drastic effect on energy consumption and peak demand in California over the last 10 years. Figure 13 shows how far demand has fallen below earlier forecasts. California electric growth had been at 6% per year from 1965 until OPEC. Gas prices went up, and the California utilities shook their heads and said, "Oh dear, that's probably going to slow down growth". They speculated that it would slow growth down from 6% to 5% per year. The 5% line on the figure was the utilities' prediction for what California would need. With that rate of increase, the state's peak demand would have swelled from 30 gigawatts in 1975 to 50 GW by 1985. More than $25 Billion would be needed to build these new plants, nearly half of which were to be nuclear.

We had begun to learn a little bit about buildings, and decided it was really cheaper to turn out the lights, particularly when people are not around. Remember, we lived in a society in which our lights always ran 8760 hours a year even though the buildings were only occupied for 3000. We at LBL came up with the idea of a "conservation potential" which said that instead of growing at 5% per year, an economic optimum was 1.2%. Of course, we knew people wouldn't invest optimally,

* The conversion from kilowatt-hours/year to average gigawatts assumes that a typical 1000-MW plant sells 5 Billion kWh/year, the U.S. average.

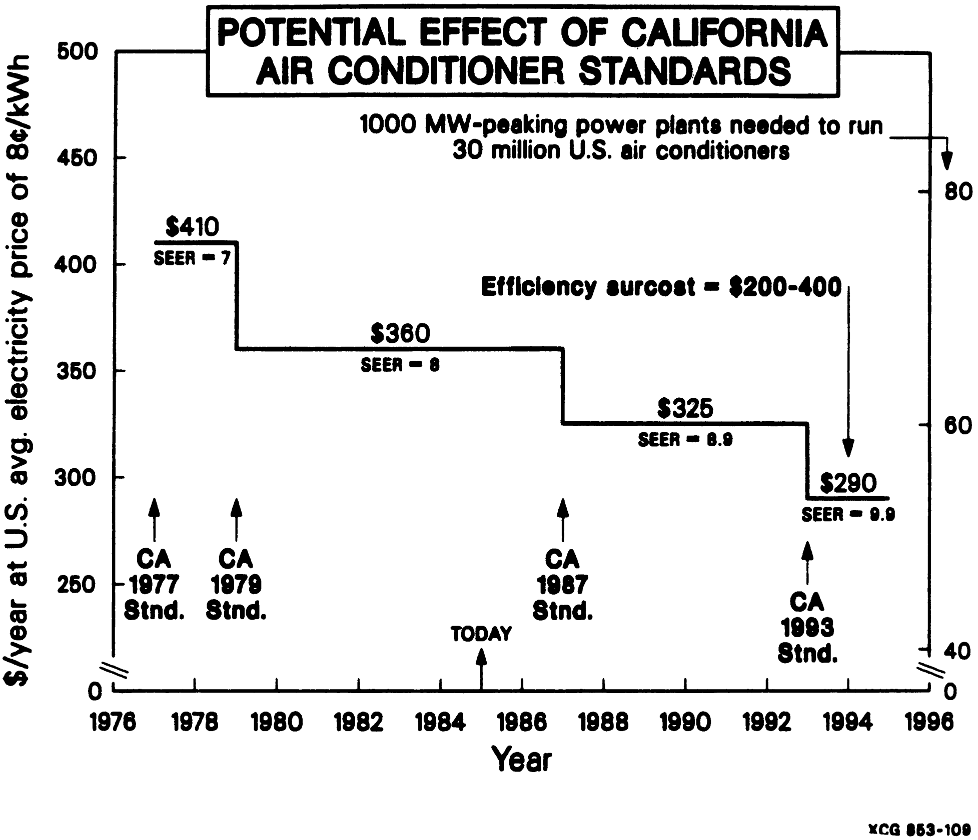



FIGURE 12. Potential Effect of California Air Conditioner Standards if Adopted Nationwide. Annual operating costs are based on SEER (Seasonal Energy Efficiency Ratings) specified by the standards for central air conditioners. The 30 million equivalent U.S. air conditioners represent 22 million actual 3-ton units and an additional 24 million room air conditioners. A typical 1000-MW baseload power plant produces 5 BkWh/year. Assuming 100 hours annual operation, the 30 million U.S. air conditioners consume 750 BkWh or 48 plants given a diversified load of 2.6 kW. Sources: Consumption - The LBL residential forecasting model (Jim McMahon). Air conditioner stock - *1984 U.S. Statistical Abstracts*, pp. 755.

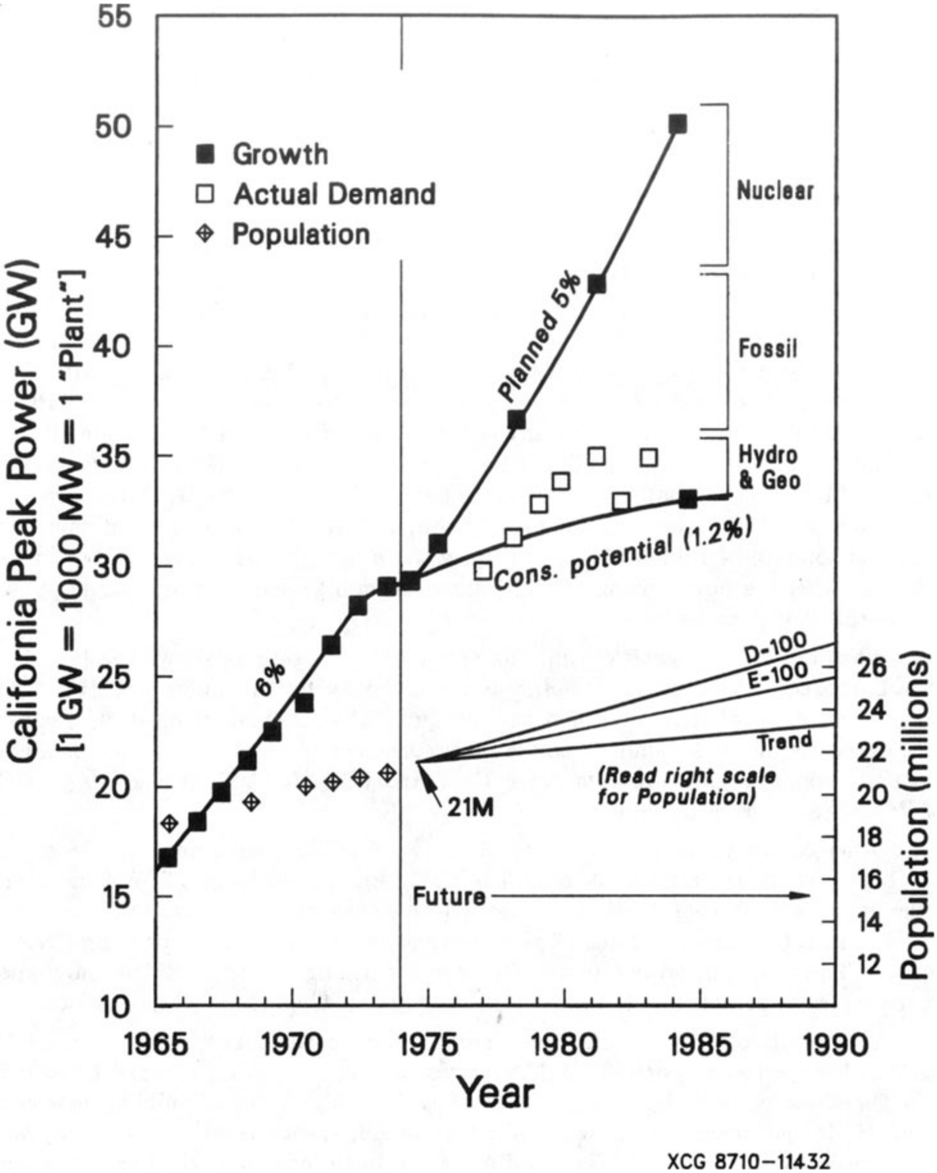



FIGURE 13. Coincident Peak Power in California. Utility projections vs. conservation potential as calculated by A.H. Rosenfeld for Warren Committee Hearings, California House of Representatives, December 4, 1975. Actual subsequent demand is plotted as □'s.

so we predicted consumption would fall somewhere in between, and suggested we could get along on 2 or 3% growth.

The □'s on Figure 13 show what actually happened—about 2% growth. Obviously it really is cheaper to turn off some lights. This figure was controversial in 1976. The president of PG&E tried to get us fired. He has since been fired himself, and we're on good terms with the utilities at the present moment; we do conservation studies for them.

### 5.4. The utility's perspective

Given the success stories we've shared, one may ask why do California utilities really want to conserve? Doesn't it interfere with their growth? It certainly disrupts one kind of growth. But California utilities have been hassled so much with standard power plants that they don't want to grow in that direction any more. PG&E paid $5.5 Billion for their Diablo Canyon nuke. Now they want to put it in the rate base and the PUC's own Public Staff recommends that the Commission only approve $1 Billion of that. It suggests that PG&E will have to "eat" the rest. No one is really going to be that tough on them, but you know that when somebody asks you to eat $4.4 Billion you're not likely to be terribly enthusiastic about investing in another big power plant. Californians just don't seem to appreciate big power plants the way they used to.

What do we do instead of building new plants? Figure 14 shows the 1981-1983 PG&E conservation program funding as approved by by the California PUC. The budget called for $124 million of programs under the headings of residential conservation service, home appliances, community consumer services, commercial and agricultural programs, and program evaluation. In 1983, $124 million was about 1.5% of PG&E revenues of $8 Billion.

Other conservation programs comprised $148 million, with another $48 million on R&D. These are big numbers. All told, PG&E was plowing 3.5% of its annual revenue back into conservation. Although that has changed somewhat now that PG&E has a temporary surplus of generating capacity, most of the programs remain intact. The most important lesson of this figure, though, is that utilities now know that they can affect demand, and they have the tools when the need next arises.

As a result of these efforts, the planning picture has taken some turns for the better. Figure 15 shows PG&E's 20-year resource plan, looking forward from 1983. The three sets of bars show a transition away from high rates of building new capacity. Hydro is forecast to grow for the first decade, geothermal grows quickly, and cogeneration is taking off. Wind and solar are increasing at a good rate but their overall contribution remains small. As for nuclear power, because of their Diablo Canyon fiasco they're not going to build any more nukes. The most interesting resource is conventional oil and steam. No new plants are planned. It turns out that no utility on the whole West Coast intends to build another thermal plant in the foreseeable future. Ten or twenty years ago, it seemed that 20% of all utility efforts went into buying land, building plants, and so on.

Figure 16 is PG&E's corresponding 20-year plan for conservation. PG&E says that its "business-as-usual" forecast with natural market improvements in conservation would cut growth down to 2.8% per year. Then state-mandated programs of various sorts will save about 1%/year more. The top layer in the graph—the very

# Summary of Estimated Conservation Expenses for 1981, 1982, and 1983

**(thousands of dollars)**

| Energy Conservation and Services Programs | 1981 | 1982 | 1983 |
|---|---|---|---|
| 1. Residential Conservation Services (including solar) | $16,577 | $34,600 | $39,400 |
| 2. Homes, Appliances and Systems | 5,820 | 9,487 | 10,527 |
| 3. Community and Consumer Services | 4,303 | 6,800 | 7,500 |
| 4. Commercial-Industrial-Agricultural Conservation Service | 15,283 | 45,000 | 65,000 |
| 5. Program Evaluation | 1,052 | 1,100 | 1,200 |
| 6. Sub-total Energy Conservation and Services | $43,035 | $96,987 | $123,627 |
| **Other Conservation Programs** | | | |
| 7. Conservation Research, Development, and Demonstration (R,D,andD) | $2,674 | $9,705 | $3,051 |
| 8. Load Management and Load Management R,D,andD | 25,257 | 60,190 | 39,791 |
| 9. Cogeneration and Solid Wastes (including R,D,andD) | 11,297 | 19,998 | 36,916 |
| 10. Conservation Voltage Regulation | 1,122 | 821 | 851 |
| 11. Energy from Biomass (Gas Production Only) | 7,272 | 17,287 | 39,833 |
| 12. General Office Departments | 18,605 | 25,100 | 27,842 |
| 13. Street Lighting Conversion | 6,053 | 3,208 | — |
| 14. Sub-total Other Conservation Programs | $72,280 | $136,309 | $148,284 |
| 15. TOTAL | $115,315 | $233,296 | $271,911 |

FIGURE 14. Summary of Estimated Conservation Expenses for 1981, 1982 and 1983 Pacific Gas and Electric Company (thousands of dollars). In 1983, PGandE revenues were $8 billion in 1983 and allocations for conservation amounted to 3½% of this total (excluding the zero-interest weatherization loan program). These percentages spent on conservation are still tiny compared with 10% Federal incentives and Tax credits available through 1986.

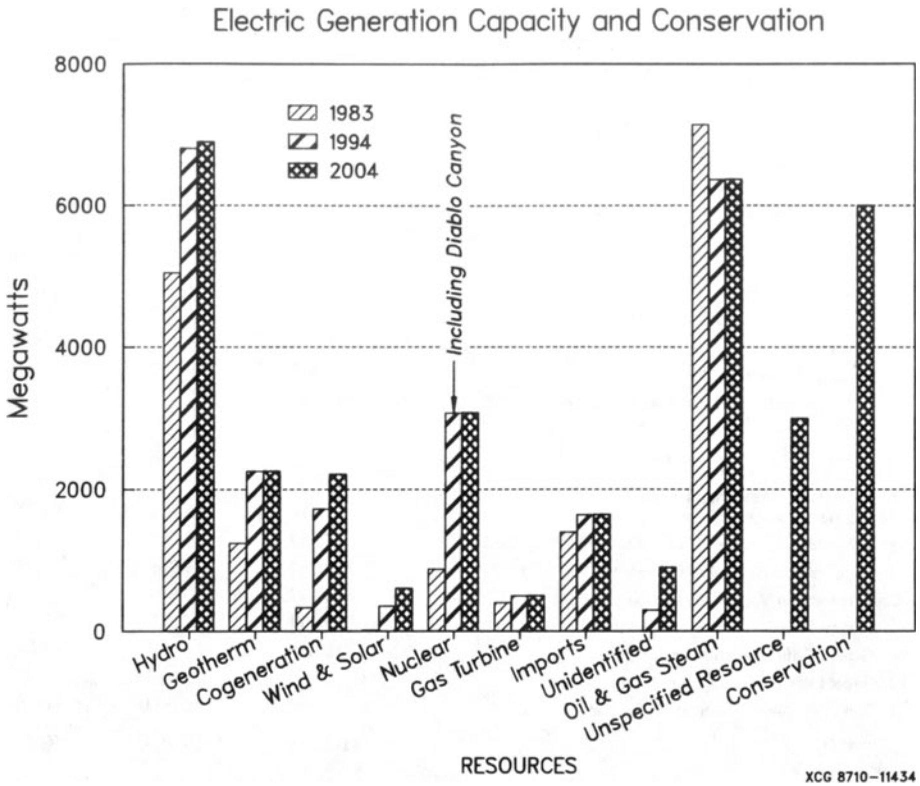



FIGURE 15. Electric Generation Capacity: Pacific Gas and Electric Company (PGandE) 20-year Plan.

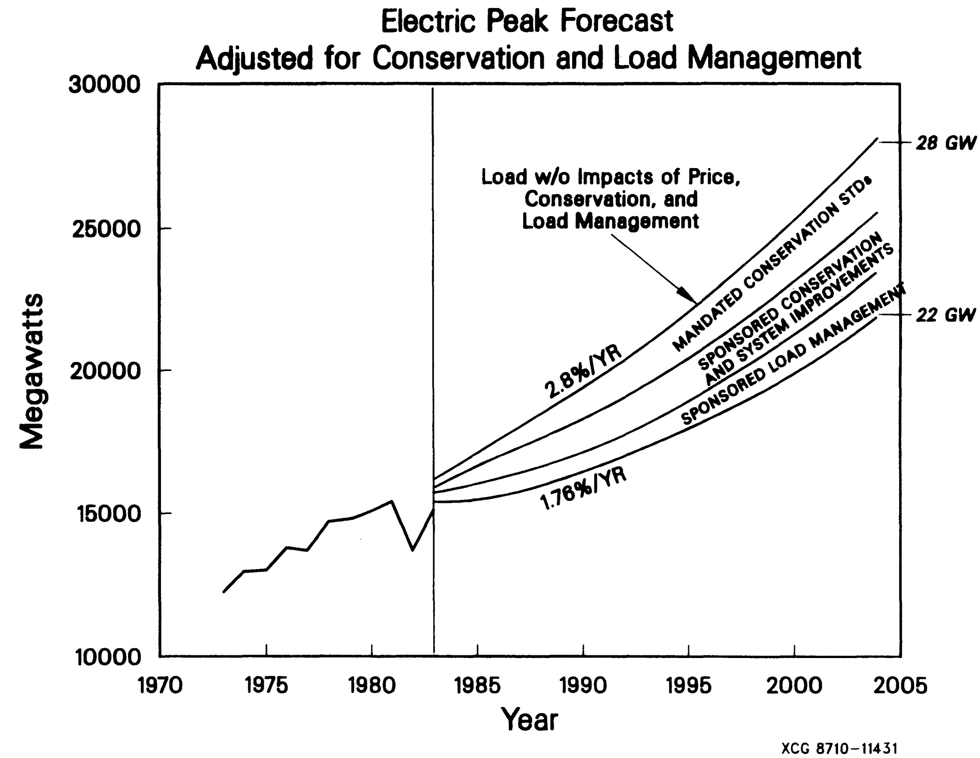



FIGURE 16. Pacific Gas and Electric Company (PGandE) Electric Peak Forecast Adjusted for Conservation and Load Management. Conservation and LM slow growth from 2.8% per year to 1.76% per year and save 6 GW (equivalent to 6 large power plants) over the 20-year planning horizon.

successful mandatory conservation standards for buildings and appliances—seem to be about a third of the story. Sponsored conservation programs are another part of the story, and so is load management (thermal storage, peak shaving). Thermal storage reduces peak load and should be good for about two gigawatts.

## 6. THE COST OF CONSERVED ENERGY

How do you calculate the cost of conserving energy with a more efficient energy-consuming device so you can compare it with energy from a power plant? Say you've got to pay $100 for the increased efficiency, but only once every 20 years. If you go to the bank and get a consumer loan in real (non-inflating) dollars at 7% real interest, for 20 years, the banker will consult a capital recovery table and charge 9.4% of the principal each year. Thus the annual cost is about $10, but the annual savings are 1200 kilowatt-hours. If you divide $10 by 1200 kWh and cancel the years, you find that the cost of conserved energy is about eight-tenths of a cent per kWh. Yet the average cost of residential electricity is about 8 cents, so in this example efficiency is ten-times cheaper than producing more electricity.

Computing the cost of conserved energy can tell us how much conservation is economically worthwhile. As we carry conservation further, the return from each improvement will tend to diminish. When the cost of conserved energy for the last increment of improvement is equal to the cost of buying new electricity, we will have conserved as much as is economically warranted. The notion of ranking conservation measures by increasing cost of conserved energy gives rise the idea of the "supply curve" of conserved energy.

### 6.1 The cost of conserved energy in refrigerators

The improvements to-date in refrigerators are far from this point of maximum cost-effective conservation. Recent studies by the American Council for an Energy Efficient Economy show that a 460 kWh/yr refrigerator would be easy to build, at a cost of conserved energy around 3 or 4 cents/kWh, and that more advanced technologies could bring the consumption down to 175 kWh/yr. As far back as 1977, A.D. Little showed that a 600 kWh/year refrigerator could be built for a $120 surcost. (Figure 17). We'll say more about refrigerators in the next section.

### 6.2. The cost of conserving one gallon in more-efficient cars

Low costs of conserved energy are not unique to home appliances. The U.S. CAFE (Corporate Automobile Fuel Economy) standards have raised the new fleet-average from 14 miles per gallon (0.17 l/km) in 1975 to 26 mpg (0.09 l/km) in 1985, but the '85 cars with their efficiency features (more forward speeds, lighter materials, etc.) retail for about $300 more (in real dollars) than cars cost in '75. Probably only $100 is for fuel efficiency and $200 is for the catalytic converter and other features to reduce emissions. The new car saves 350 gallons per year. At a dollar per gallon, the payback time is one year. If you calculate the cost to conserve gasoline, it is 10 cents per gallon. We assert that most of us are quite happy to conserve gasoline at 10 cents per gallon rather than buy it at a dollar per gallon.

The savings we have achieved at that cost are substantial. Figure 18 depicts the declining fuel consumption of the increasingly efficient U.S. car fleet. Considering that the average car is driven 10,000 miles a year, the graph shows how the

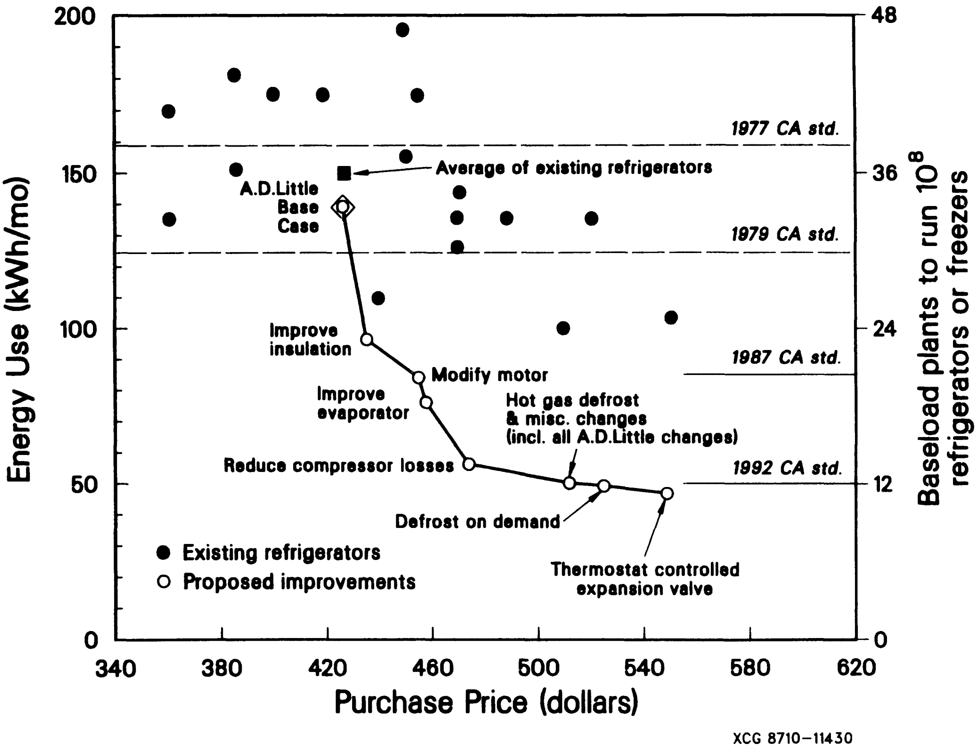



FIGURE 17. Electricity use vs. Purchase Price for Existing and Proposed Refrigerators. The closed circles in the upper half of the figure represent 17-17.5 cu. ft. top-freezer, automatic defrost models sold in California in 1976. The open circles joined by a heavy line are improved design steps proposed by A.D. Little (May 1977). All U.S. refrigerators plus freezers in 1980 used about 140 BkWh, so the vertical scale can also be read in BkWh, for the U.S. The potential savings of 85 BkWh is equivalent to the output of 17 1000-MW baseload power plants.

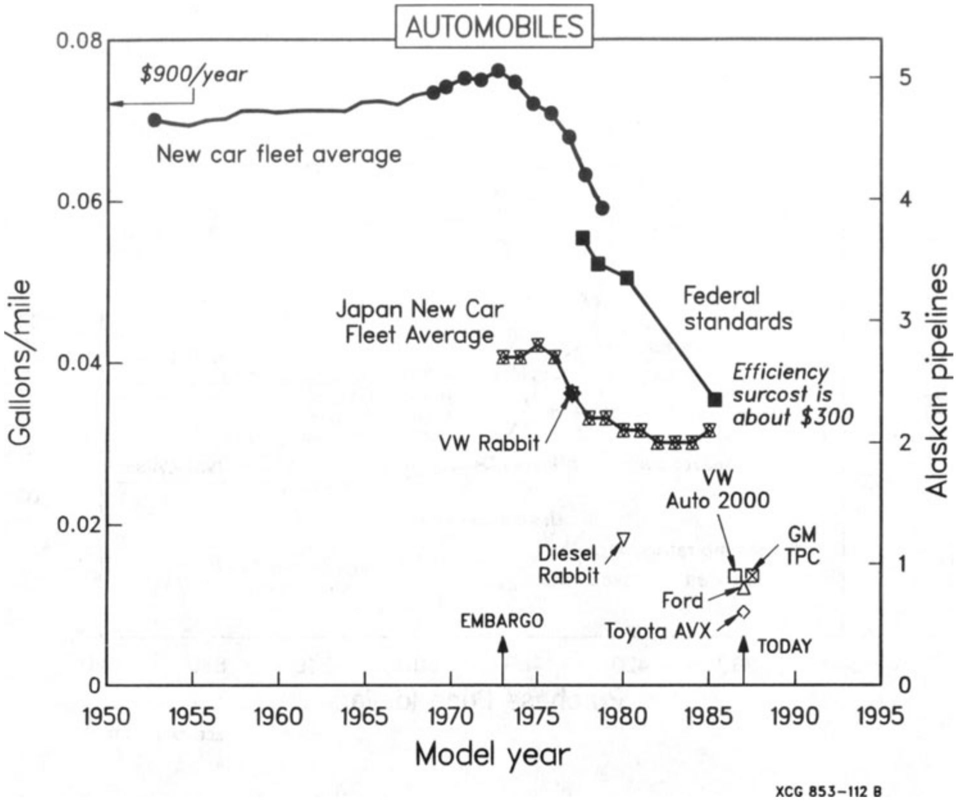



FIGURE 18. Automobile Energy-Use Trends: 1952-1985. The right-hand axis shows the equivalent number of Alaska pipelines required to fuel the U.S. auto fleet at various average efficiencies. The 1983 average fuel efficiency for autos was 16.7 mpg or 0.06 gpm, or 6.7 Mbod for the 1983 auto fleet. The Alaska Pipeline produces 1.7 Mbod; so in 1983 autos were using nearly 4 Alaskas. One Alaska corresponds to an average fleet efficiency of 0.015 gpm (or 60 mpg). Since the oil embargo, Japan's average fleet-efficiency been about twice as good as in the U.S., but the gap has narrowed slightly. The left scale reflects annual operating costs assuming $1/gallon and 10,000 miles driven per year. Federal standards will continue the trend of voluntary efficiency improvements which took place during the late 70's. Some of the more-efficient cars on the market or at the prototype stage are shown for reference. Source: Efficiency - "The Fuel Economy of Light Vehicles," Charles L. Gray, Jr., and Frank von Hipple, *Scientific American*, May 1981 vol. 244 No. 5. Alaska Pipeline production - Annual Energy Review (EIA-0384) 1984. US fleet Average (passenger cars) - Monthly Energy Review (EIA-0035) June, 1987. Japan Data - "Energy Conservation in Japan," The Energy Conservation Center, Tokyo 1986.

annual cost of gasoline to fuel that amount of driving has declined and how much of an improvement that translates into nationwide. We like to use a convenient large unit to think about oil use, which is the amount of oil moved through the Alaska pipeline—about one and three-quarters million barrels per day. By that yardstick, if American cars and light trucks still operated at their 1973 efficiencies, we would need five Alaskas just to run the auto fleet. As it is, in another five years, by the time the pre-CAFE cars are off the road, we'll be down to about two and a half Alaskas. And when we get to where the Volkswagen and other prototypes are taking us, we'll be using no more than about one Alaska. Of course, if it's not Volkswagen, it will be Fiat or Volvo or some other car-maker based in a country with a $1 to $4-per-gallon gasoline tax. Volvo has a car that has passed the California crash tests that gets 65 mpg (0.04 l/km), and Fiat is working on 130 mpg (0.02 l/km). We won't hold our breath for Ford.

## 7. APPLIANCES: PROGRESS AND POTENTIAL

The difference between the "fleet-average" of existing appliances in the U.S. can be improved by 50-75%. The new national standards will eliminate the real gas guzzlers, but the standards are well exceeded by the best models on the market and by the technical potentials for appliances. Figure 19 was made by Howard Geller of the American Council for an Energy Efficient Economy. The lower half examines the potential for improved central air conditioners, room air conditioners, water heaters, freezers, and refrigerators.

Let's look at central air conditioners. In kilowatt-hours per year, the highest column represents "stock". That is, it's the average unit in use at the latest survey that Geller could find—probably 1985. It's labeled around 3700 kilowatt-hours per year. The next block, at about 2900, shows how much energy was used by the average new unit on the market in 1985. This is partly thanks to the California standards, and partly because electricity prices were going up. Air conditioners are getting better, and at quite a clip: about 22% in 10 years. The next block—1800 kWh/yr—represents the best on the market in 1985. If you had done some comparison shopping, you would have ended up getting that one. The lowest block—1000 kWh/yr—is the best on the Japanese market or the best on the drawing boards. You can see that there's still a lot of progress to be made.

Electric water heaters tell the same story. The tallest bar is the average stock electric-resistance water heater at 4000 kWh/yr. The next smaller, at 3500 kWh/yr, is a better insulated one. Below that (1650 kWh/yr) is a heat pump and the smallest (1200 kWh) is a more-efficient heat pump. The story is the same for refrigerators and freezers, as well as lighting. In clothes drying, enormous improvements are possible even without switching to gas.

Following California's lead, the federal government has promulgated its own standards. The history behind these standards was somewhat messy. The U.S. Congress first required the Administration to set national appliance standards in the waning years of the Carter presidency. The standards were all written, but Mr. Carter lost his nerve and Mr. Reagan decided they were a poor idea.

This produced a backlash in which various states started passing their own appliance standards. That worried the manufacturers because they were faced with a patchwork of 50 sets of contradictory appliance standards instead of one national

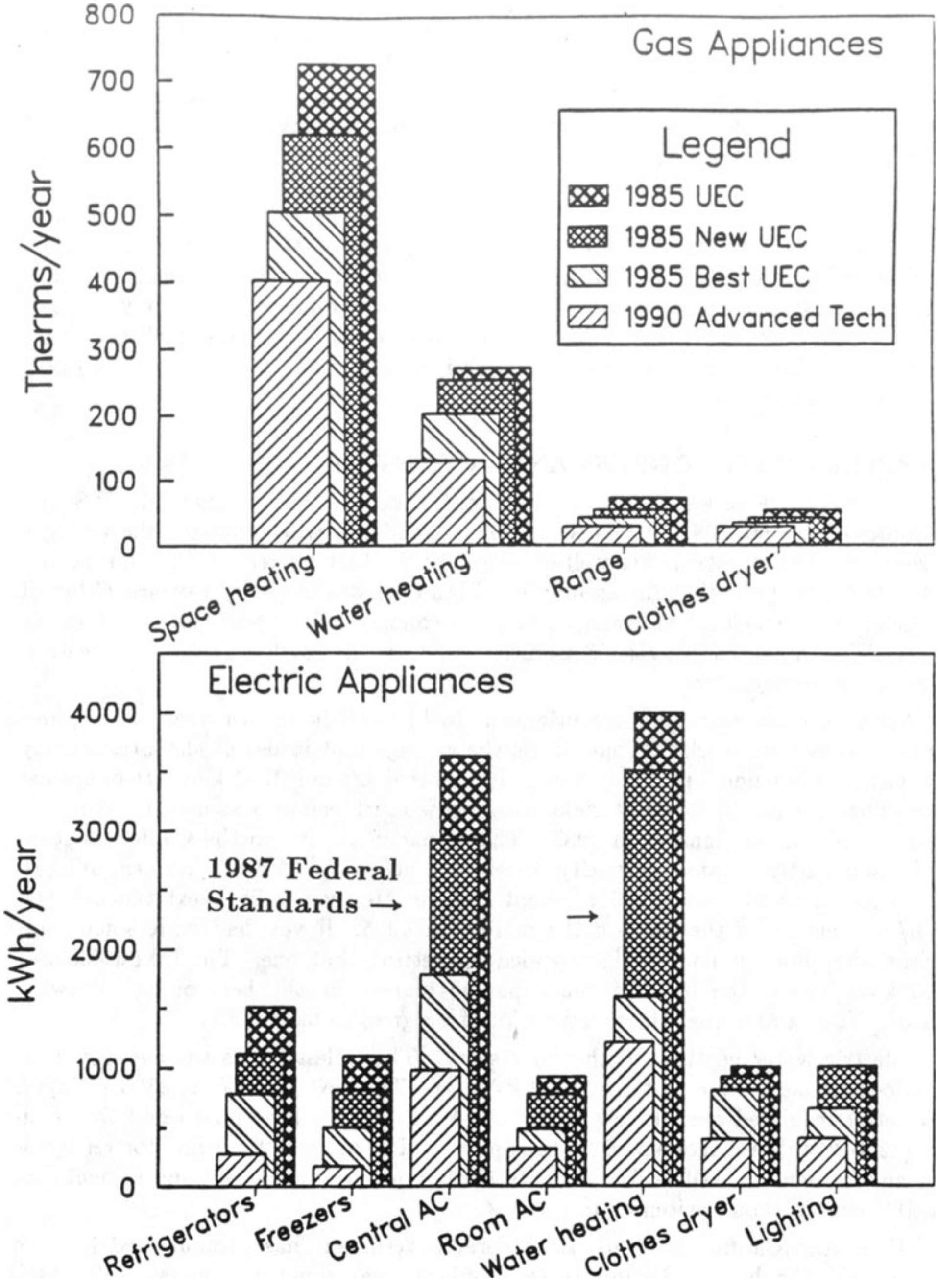



FIGURE 19. Unit Energy Consumption of Gas and Electric Household Appliances in the U.S. Each set of bars compares energy use by the average model in the 1985 stock, the average new unit and best new unit sold in 1985, and the best technology expected to be available in the 1990s. For scale, note that the electric appliances sold in one year use as much electricity as is produced by six large, 1000-MW power plants. This would drop to 2 power plants if all new models were as efficient as the best 1990s technology. Source: American Council for an Energy-Efficient Economy.

standard. They then appealed to DOE to recommend national standards, but DOE refused. Amazingly, the manufacturers then sat down with the Natural Resources Defense Council (a leading environmental and clean-energy group) and agreed on appliance standards very similar to the ones currently in effect in California. Congress passed the package unanimously in June 1986, but Mr. Reagan vetoed it. Then it came up again in spring 1987, and Mr. Reagan decided the handwriting was on the wall and he'd better pass it. We now have *national* appliance standards which will gradually come into force.

Arrows and the notation "1987 federal standards" on Figure 19 mark the levels of the new federal standards for central air conditioners and water heaters. You can see that the standards are not particularly stringent, and don't require manufacturers to develop new, unproven technologies. The payback time on those standards is fairly short—about two years. They don't place any onerous demands on consumers or manufacturers; they simply keep the worst junk off the market and prevent it from loading down the utility grid for the next twenty years.

## 8. ENERGY CONSERVATION IN THE BUILDING FABRIC

Naturally, the way a building is designed has a lot to do with how much energy it will use over its lifetime. In contrast with the rest of the United States, California is one of the few states that actually have performance standards for new buildings. In the U.S., the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) passes voluntary standards. These are upgraded every few years and are called ASHRAE Standard-90 Series. They tend to be adopted by about half the states, but we're not sure if there is any actual enforcement. In California these standards are enforced, and have been strengthened substantially with a statewide code called Title-24—the most flexible and forward-looking in the country. The code allows builders to either conform to one of a series of packages, or to design a building and simulate its energy use to show that it would not use more energy than the allowed budget. There's even a "point system" that allows builders to come up with innovative designs without having to use computer models to show that they meet the standards.

Earlier, we showed something that most Americans are proud of, which is the progress in automobiles. Now, we want to show that the progress in commercial buildings is more astounding, cheaper, and conserves more fuel. But we're all much more aware of automobiles because we've all waited in line at the pump. We want to point out that the resource energy used by automobiles (motor gasoline) in the United States is about 10 quads or maybe 12, and commercial buildings is 12 quads also. So they're both serious gas guzzlers.

Figure 20 shows how energy use in large office buildings has changed since World War II. In the years of abundance from 1950 to 1973, resource energy use in new American buildings roughly doubled—that's the grey band. After the oil embargo of 1973, a few commonsensical measures led to significant improvement: ideas like not trying to heat and cool the air simultaneously or turning out the lights when no one is in the building. With the aid of voluntary federal standards and mandatory ones in California, we have pared energy use back even further by trying to design buildings that actually make sense. Designers have used daylighting, improved ventilation, intelligent fenestration (instead of simply enclosing the entire building in glass) to reduce the resource energy use of a building to almost a third of

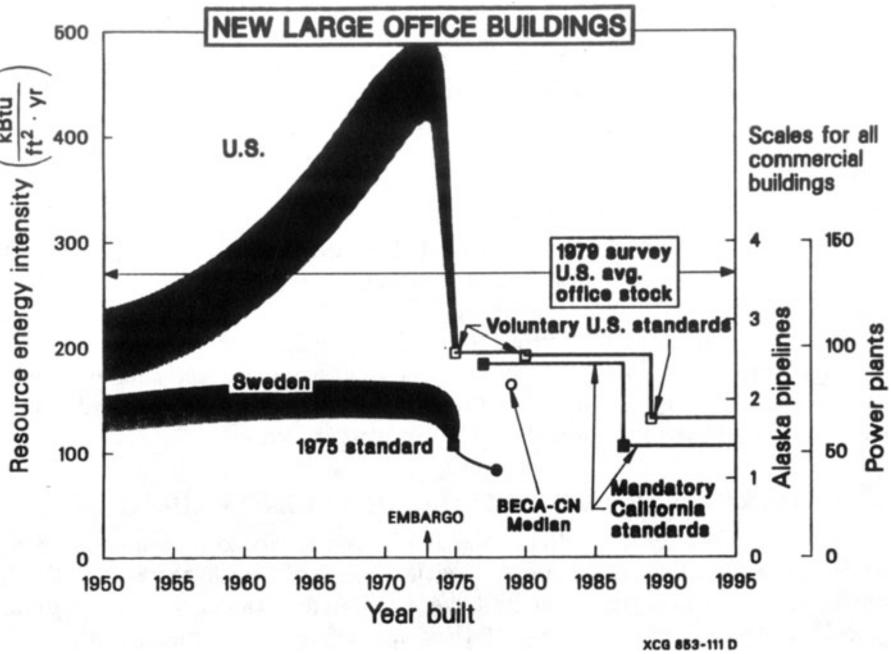



FIGURE 20. Trends in Annual Energy Intensity (use per $ft^2$) of New Office Buildings. Electricity is counted in resource energy units of 11,600 Btu/kWh. Dots represent data from real buildings. Squares are computer simulations from prototypes. Thus, the U.S. sequence is represented by a broad shaded band and is a crude measure of New York City office buildings by Charles W. Lawrence, Public Utilities Specialist for the city of New York (1973). The 1973 (pre-embargo) square is a simulation by A.D. Little for FEA; the later squares are simulations of buildings conforming to the indicated standards. Sources: A.D. Little, FEA Conservation paper 43 B (1976), and ASHRAE Special Project 41, Vol. III. DOE/NBB 51/6(1983). LBL ID No. XCG 853-111 D.

what the average office tower required in 1979. When these changes capture the entire market, we will be saving another two and a half Alaskas, or about 90 power plants. By way of comparison, the figure shows the experience in Sweden where in fact they tried a few American-style buildings, but they didn't sell. And so they've run with the same amenity for about half of the energy use.

It is also interesting to plot this picture in two dimensions and look at fuel versus electricity use during the 70s. What we have in Figure 21 is electricity in kilowatt-hours per square foot on the horizontal axis and fuel, in thousands of BTUs per square foot, on the vertical axis. Note the United States office stock as taken from a survey in 1979. The typical building used about 17 kilowatt-hours per square foot annually, but a fair amount of fuel as well—nearly 70 thousand BTUs per square foot annually. In dollars, that's about $1.20 worth of electricity every year and another 80 cents' worth of fuel.

Use came down quickly under the ASHRAE standards to less than 15 kilowatt-hours per square foot and virtually no oil. The progressive California standards—to take effect this year—will cut the electricity use again in half. The figure also depicts the residential stock where electricity use has always been low and the savings are only about 20%. However, the use of insulation in homes has saved enormous amounts of fuel.

## 9. THE UTILITY ROLE IN CONSERVATION

### 9.1. Marketing and incentives

Let us say a few things about marketing and incentives. First of all, what our utility—PG&E—has discovered is that if a utility wants to get something done they have to do more than just rely on prices or tax incentives. To *really* encourage conservation, PG&E has implemented incentives for refrigerators and new housing.

For new efficient refrigerators, they pay a $25 incentive to the buyer and another $25 to the seller. In addition, there has been an enormous advertising effort. In fact, PG&E took out full-page ads in the San Francisco Chronicle and only ran them for two days because that's how long it took for the efficient refrigerators to clear off of the shelves.

On energy-efficient homes, the utility program beat the Title-24 standard we described earlier by 10%. By beating the standard by up to 10%, the builder got a plaque; by beating the standard by more than 10%—and they had the builders exceeding Title-24 by more than 30% with a payback time of only one year—the builder got a label for the home and points for utility bill savings and was paid 15 cents per kilowatt hour, per year saved (Figure 22). An extra and unexpected benefit was that builders found that the labeled homes sold better, the more points the faster the home sold. PG&E found that this approach worked much better than the flat $175 incentive that they previously had offered to builders.

Why incentives when standards are available? The Title-24 standard took several years to implement. The buildings constructed under the new standards would be much more efficient than the previous generation. Their peak power load was going to be 4 to 4.5 watts per square foot, instead of something like 6 or 7 watts per square foot. PG&E knew that it was much cheaper to invest a few percent more in a building to get that efficiency rather than build the power plants to go with the

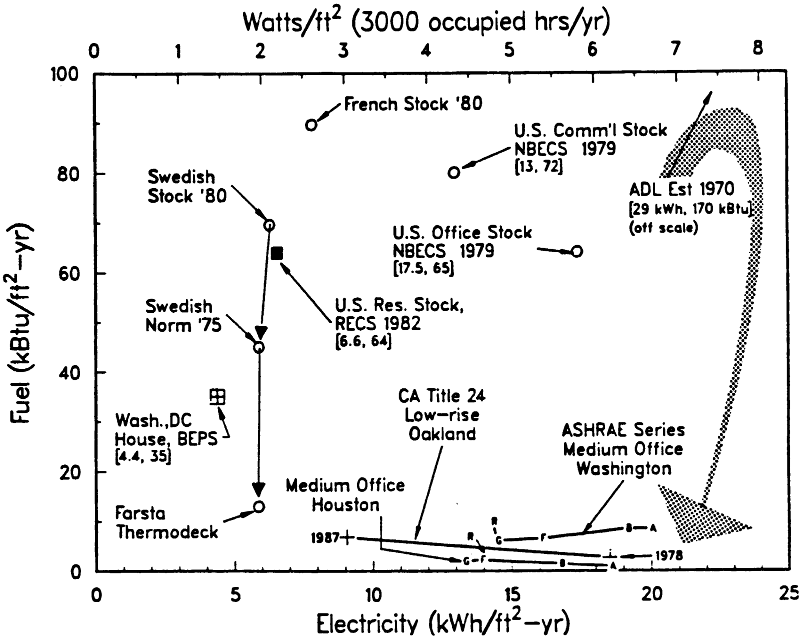



FIGURE 21. Office Building Fuel and Electricity Trends. Office buildings have such a large amount of "free" heat from equipment and people that they now need almost no space heating, even in climates as cold as Sweden's. So, modern office buildings are becoming almost entirely electric. Thus, the sequences labeled A, B, F, G, and R representing *modern office building* prototypes (conforming to the voluntary ASHRAE Standard 90 Series) *are almost lost at the bottom of the figure.* Similarly for the two-point sequence representing the California Title 24 mandatory standard. Real buildings have been found to use 10-20% more energy than that called for by standards. For comparison, residential trends are shown at the left. Sources: NBECS, the "Non-Residential Building Energy Consumption Survey," DOE/EIA-0318(79) and RECS, the "Residential Energy Consumption Survey," DOE/EIA-0321(81). The various standards are described in ASHRAE Special Project 41, DOE/NBB-0051/6.

Key to symbols: Open circles represent measured data, +'s and letters are calculations based on prototypes.

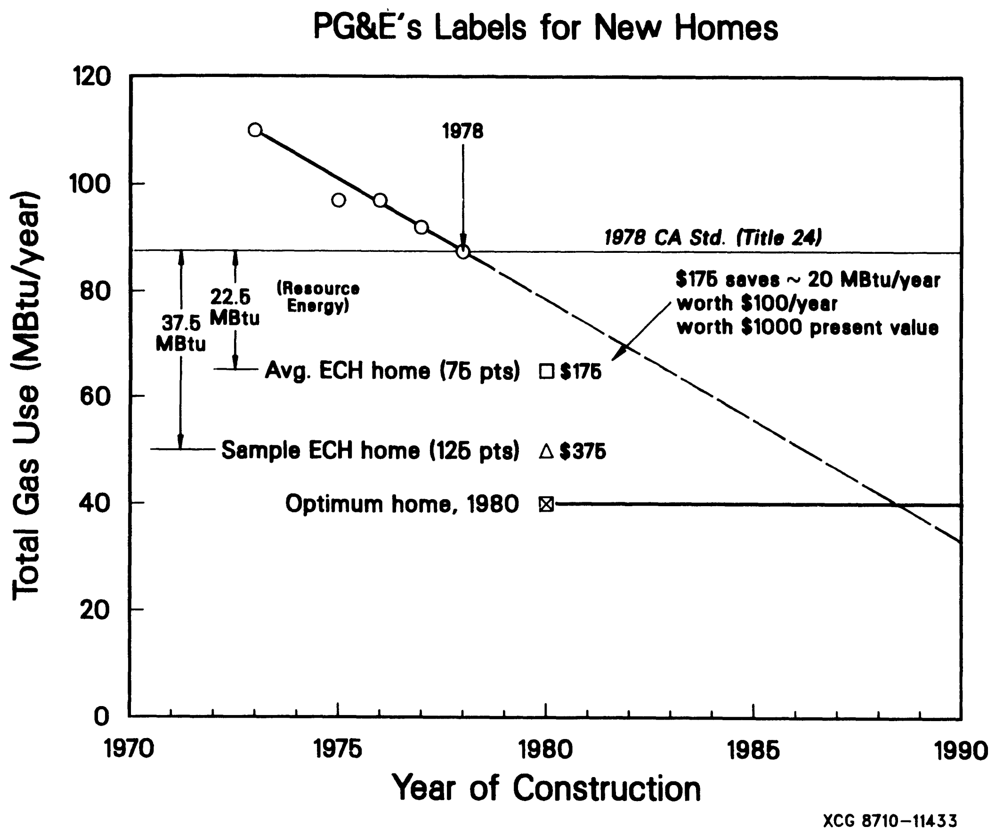



FIGURE 22. PG&E's Labels for New Homes. The y-axis shows total use of gas. The open circles are average billed use of gas and the solid dot is the calculated gas use of the average home qualifying in 1980 as an Energy Conservation Home; 60% of all new homes qualified. The average home in the program saved $100/year at an incremental cost of $175—these savings are worth $1000 in terms of net present value. The "+" is the sample Energy Conservation Home's score according to the labeling system. The "x" is the estimated use for a home built today in Fresno, California's climate that minimizes its lifetime costs. In 1980, Presley Homes currently advertised that its homes were as good as this least-cost optimum. The thick horizontal line is the economic optimum energy use, on the assumption that gas and gas conservation costs remain constant in real dollars. Given the trend suggested by the measured data, new homes would not reach the optimum until the late 1980's. Buyer-information programs, such as labeling, can accelerate the shift to more efficient home design. Economy and the Energy Conservation Coalition. March 4, 1986.

building. PG&E said, "Well, if we can save a kilowatt on a new building, we save ourselves $1500," which was their estimated marginal cost for production, transmission, and distribution. They could easily afford to bribe the building owner $300 per kilowatt to do that, and they would still be way ahead with the rate payers.

Of course, the building lasts a long time. Power plants only last 30 years, or with good luck, 50 years before replacement. Buildings last 50 years and homes last 100 years. It's very important to build right to start with. It's hard and more expensive to fix them later. So PG&E said, "Okay, if you build buildings which beat existing codes and conform with the new Title-24 early, we'll pay you $300 per kilowatt up to $50,000. That should be enough to get your attention". And so was launched a very successful program. They encouraged thermal energy storage, too, because it is very attractive to the utility as a way to sell off-peak power at night and it avoids the construction of new power plants. The rebate was about $300 per kilowatt saved, up to $150,000 per building.

Incidentally, the payback times are very short. It's like shooting fish in a barrel. Some of the payback times on these thermal storage projects are well under a year. In fact, some of them are negative, since builders can save more by downsizing their chillers to run around the clock than it costs to install the thermal storage itself. Despite the essential attractiveness of these investments, the utilities were still willing to offer the $300/kW incentives.

Actually, San Diego Gas and Electric is even cleverer. They said, "Why should we be spending ratepayers' money to encourage people to make an investment that will pay back in three months anyway?" Instead, they guaranteed a three-year return on investment. They figured that people would undertake improvements with two-year paybacks without any utility incentives. By guaranteeing the three-year payback, they bribed customers to go further and pay for measures that are not as dramatically cost-effective, (the two- to three-year paybacks) in order to get the utility to cover the three-year and longer paybacks.

PG&E's incentives for the commercial sector are all very carefully tuned. They don't want to pay more than necessary; they just wanted to get the audience's attention. The program was aimed at encouraging energy-efficient motors in small commercial or residential buildings. If it's a small one, they'd pay up to $60, or about $300 a kilowatt. If it's a larger one, they'd pay $10 per horsepower, which worked out to $100 per kilowatt in terms of savings. This was a very well-tuned program with lots of feedback in which they try to avoid wasting too much of the ratepayers' money and still get the customers' attention.

We've talked a lot about California. But demand-side planning is much more widespread and we will mention one other significant U.S. effort. In the Pacific Northwest, under the auspices of the Bonneville Power Administration, the utilities are also testing and recommending building standards. And they have many incentive programs. A program much like PG&E's was described in a recent July 1986 "Northwest Energy" newsletter, where incentives are held out specially for early-adopters of a new buildings standard. That is, they have some standards ready, they want people to experiment with them ahead of time, and they will pay builders and developers order of magnitude, $10,000 to $100,000 for experimenting with the new codes as they build new buildings. They'll pay up to $100,000 for training county code supervisors to keep up with their new codes. And we think planners will find this investment in training and enforcement to have a payback closer to

**TABLE 4.**
**Project Merlin:**
**The Potential for PGandE to Defer a Residential Power Plant**

**ENERGY**

| | 1985 (BkWh) | 2005 (BkWh) | Fraction of PGandE Model |
|---|---|---|---|
| **All End Uses** | | | |
| PGandE End-Use Model | 22 | 28 | --- |
| **7 Main End Uses** | | | |
| Same Model | 15 | 21 | 100% |
| Potential (current technology) | --- | 16 | 77% |
| Technical Potential | --- | 12 | 56% |

**SUMMER PEAK POWER**

| | 1985 (GW) | 2005 (GW) | Fraction of PGandE Model |
|---|---|---|---|
| **7 Main End Uses** | | | |
| PGandE Model | 3.7 | 5.8 | 100% |
| Potential (current technology) | --- | 4.0 | 69% |
| Technical Potential | --- | 2.5 | 43% |

Notes:

Measures were included if their cost of saved electricity was less than 10¢/kWh. Power-conserving measures were included if their avoided cost of peak power was less than $1165/kW. This avoided cost was annualized over 20 years (the assumed life of a new power plant). A typical 1-GW baseload plant sells about 5 BkWh/year. Source: "Residential Conservation Power Plant Study," American Council for an Energy Efficient Economy. February 1986.

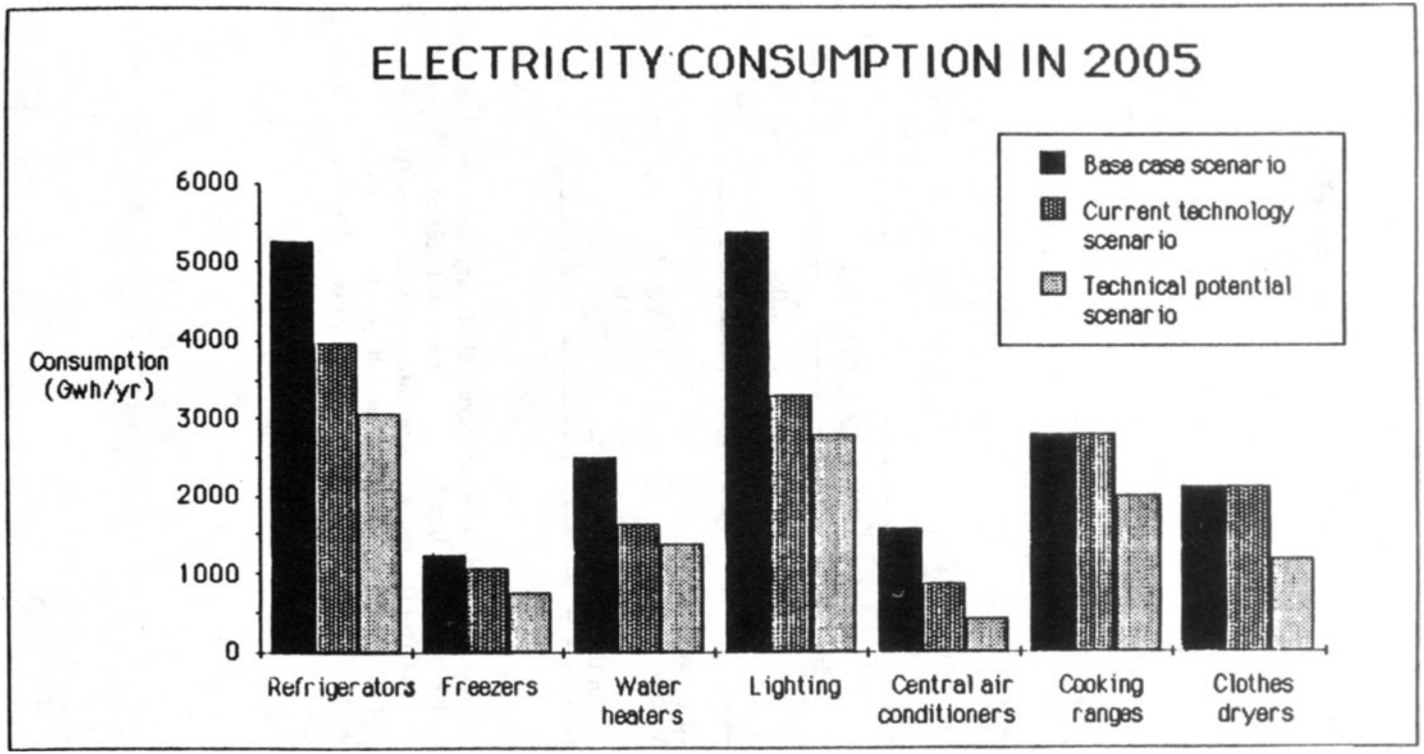



FIGURE 23. Project Merlin Results: Pacific Gas and Electric Company (PGandE) Residential Conservation Power Plants. The y-axis shows electricity consumption in the year 2005.

one-month. Because if they advance a major program by a year, they've saved a lot of energy very cheaply.

### 9.2. Merlin the Magician

The residential sector offers opportunities for large-scale demand management. PG&E had two planned unspecified power plants—which they called "Merlins"—to meet expected growth in residential demand (the bar labeled "unspecified resource" in Figure 15). Merlin is a nice name, because Merlin was a magician who sometimes appeared and sometimes didn't. And it turned out these Merlins don't have to appear, thanks to a couple of gigawatts' worth of conservation potential that the Merlin study team uncovered using nothing but currently available, off-the-shelf technologies. As shown in **Table 4**, they could save another gigawatt or so in the residential sector once some of the technically feasible efficiency measures are commercialized and implemented. In fact, the chief Merlin planner at PG&E, Lee Calloway, now has big pictures in his office of virgin forest, one's labeled "Merlin Site I" and the other's labeled "Merlin Site II".

The Merlin project plan was to invest in conservation measures that had a cost of conserved energy up to 5 cents a kilowatt-hour or in conserved power up to $1500 a kilowatt, both of them being cheaper than existing supply prices. We started with PG&E's latest resource plan and their end-use model, which is what they thought had all the latest technology from standard sources like EPRI. We couldn't look at everything in the model, we didn't have the resources to do that, but we looked at the seven main uses of residential electricity. Figure 23 shows the savings scenarios for each home appliance.

We found that, in fact, PG&E had missed some 5/16 or 20% of the available conservation options, and that they could cut their energy demand by about another third. And if one took what was known in technology, that is, what's on the drawing board now and probably will be available by the end of the century, in fact the gains were about 50%.

So this is a dynamic field, and it's an argument that shows that if you conduct studies like Merlin that you'll find that a lot of things can be done. If you don't conduct the studies, your plans will surely be wrong and your ultimate cost of providing energy services will be higher than necessary. The point is brought home when, in their 1984 annual report to stockholders, PG&E describes how they spent $250 million per year on conservation. It adds up in the last five years to over $1 Billion. But they say it has avoided the need to commit $7 Billion to new plants. They think the customers and stockholders should be happy. That's basically what we've learned to do: concentrate on conservation where it provides energy services at least cost.

### 9.3. Michigan's Merlin

All the pieces of this least-cost resource planning approach were recently brought together in LBL's *Michigan Electricity Options Study* (MEOS). We did a thorough evaluation of the residential sector in the Detroit Edison and Consumers Power territories [for more details see the case study by Krause, Colborne, and Rosenfeld in Chapter 7]. We found a great gap between frozen efficiencies and the least-cost potential. We filled this gap with a supply curve of conserved energy

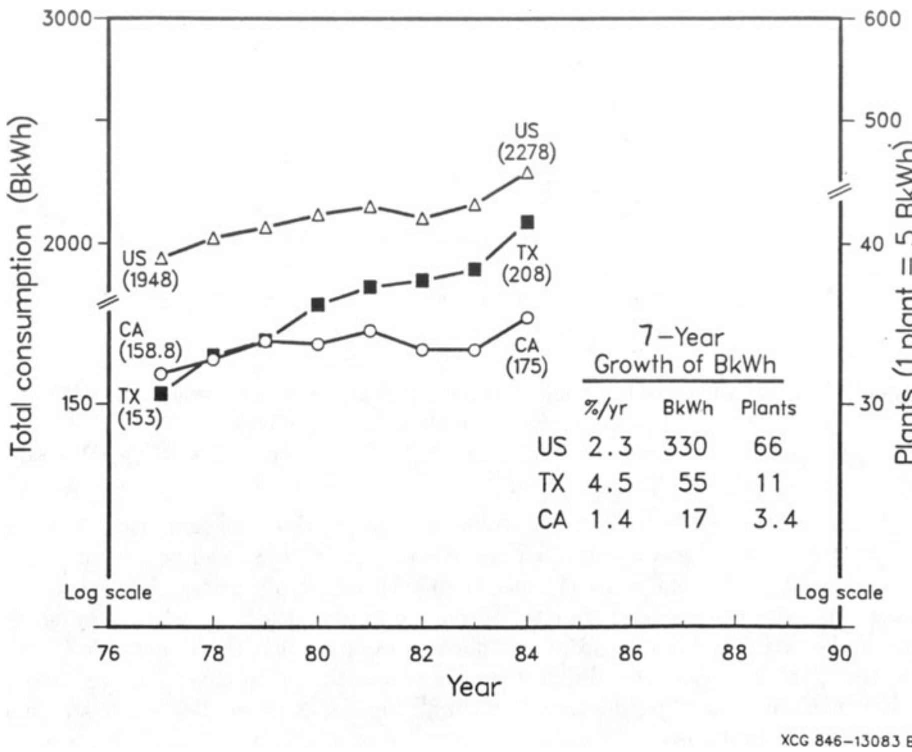



FIGURE 24. Total Electric Consumption by All Customers For CA, TX and the U.S. Comparative populations in 1984 were: CA 25.6 M and TX 16.0 M. In the seven years 1977-1984, annual growth rates were: CA 2.0% and TX 2.8%; TX - CA = 0.8%, whereas for annual BkWh growth, TX - CA = 3.1%. Electricity price increases in TX were less than one percent greater than in CA. The y-axis is logarithmic and the U.S. is shifted down one decade. BkWh are converted to 1000 MW (1 BW or 1 GW) using "1 Plant" = 5 BkWh/year. Sources: Consumption—Electric Power Annual (EIA 0348(84) p. 124 and EIA 0348(82) p. 167). GW—Annual Energy Review (EIA 0348(83) p. 195 and 201.)

amounting to nearly 700 Megawatts. In our program scenario, we deployed the measures until their cost of conserved energy rose to the cost of new power supply. This is the efficient way to do it. We then incorporated the lags in consumer response based on our experience with other conservation programs around the country and accounted for appliance retirements and new additions.

## 10. CLOSING THOUGHTS

What has it all added up to? Figure 24 sets the stage for a final comment on California conservation. We made this plot when we were trying to sell conservation plans to the Texas Public Utilities Commission. Whether it makes Texans feel bad or Californians feel good, it does seem to show there's a difference. From 1977 to 1984, California's use of electric energy was almost flat, while Texas's consumption grew at 4.5% per year and consumption in the United States as a whole increased at 2.3% per year. (U.S. consumption is divided by 10 so we could get it on the same scale). We observed that in two states which are very similar—both sun-belt states, both growing in economic productivity about 4% per year, both growing in population about 1% per year—the only important differences are that California has a serious energy policy and its electric needs are barely growing. Texas is a very laissez-faire state that hardly enforces policies on anything. It's not just energy. Texas, the day we made this plot, was the only state we know of where you could drive legally with an open bottle of beer in your car. When it comes to energy, one of the prices they seem to have paid is that for the same economic growth, we in California in seven years added the need for 3.4 power plants; the Texans needed 11. [5] That's a difference of seven power plants for a total of over $10 Billion, and that's the price you pay for sticking your head in the sand. Let this be a lesson to us all.

## ACKNOWLEDGEMENTS

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